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Mod-5A Wind Turbine Generator Program Design Report

Volume III—Final Design and System Description
Book 2

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General Electric Company
(Advanced Energy Programs Department)

August 1984

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract DEN 3-153

for
U.S. DEPARTMENT OF ENERGY
Conservation and Renewable Energy
Division of Wind Energy Technology

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Volume I, Executive Summary

Volume I contains an overview of the MOD-5A Program. These topics are covered:

- Objectives of the MOD-5A Program
- Description of the Final Design (Model 304.2)
- Cost of Energy
- Power Output
- Trade-Off Studies
- Development Tests
- Analyses of Loads and Dynamics
- Manufacturing and Quality Assurance and Safety Plans

Volume II, Conceptual and Preliminary Design

These sections comprise Volume II, which is divided into two books, as follows:

Book 1 1.0 Summary
2.0 Introduction
3.0 Design Requirements
4.0 Conceptual Design Studies
5.0 Design, Development, and Optimization
6.0 System Dynamics Analysis
7.0 System Loads Analysis

Book 2 8.0 Development Tests
9.0 Design Criteria
Appendix A System Specification
Appendix B Design Load Tables

Volume III, Final Design and System Description

These sections comprise Volume III, which is divided into two books, as follows:

Book 1 1.0 Summary
2.0 Introduction
3.0 System Description - Model 304.2
4.0 Rotor Subsystem
5.0 Drivetrain Subsystem
6.0 Nacelle Subsystem
7.0 Tower and Foundation Subsystems

Book 2	8.0	Power Generation Subsystem
	9.0	Control and Instrumentation Subsystems
	10.0	Manufacturing
	11.0	Site and Erection
	12.0	Quality Assurance and Safety
	13.0	FMEA, RAM and Maintenance
	Appendix A	C.F. Braun & Company - Foundation Design Criteria
	Appendix B	GE - Product Assurance Program Plan for the MOD-5A WTG Program
	Appendix C	GE - System Safety Plan for the MOD-5A Program
	Appendix D	GE - MOD-5A Configuration Management Plan
	Appendix E	GE - MOD-5A Defect Reports for Development Hardware
	Appendix F	GE - MOD-5A Program Quality Assurance Requirements for the Control of Raw Materials and the Blade Fabrication Process
	Appendix G	GE - Statement of Work for the Erection of the MOD-5A WTG Yaw, Nacelle and Blade Subsystems

Volume IV, Drawings and Specifications

This volume contains the numbered drawings and specifications for the final design of the MOD-5A wind turbine. The volume is divided into five books, as follows:

Book 1	47A380002 through 47A380030
Book 2	47A380031 through 47A380068
Book 3	47A380074 through 47A380126
Book 4	47A380128 through 47A387125
Book 5	47D381002 through 47D387130

MOD-5A WIND TURBINE GENERATOR
DESIGN REPORT
VOLUME III, BOOK 2

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8.0 POWER GENERATION SUBSYSTEM

8.0 POWER GENERATION SUBSYSTEM

This section describes the power generation equipment and auxiliary electrical equipment on the MOD-5A wind turbine. The control and instrumentation equipment is described in section 9.

The selection of the variable speed generator and the basic design criteria for the power equipment are discussed in section 8.1. The main electrical components are described in the subsequent sections. The utility interface is described in section 8.13.

8.1 POWER GENERATION, DESIGN CRITERIA

The MOD-5A design started with a salient pole synchronous generator for the conversion of shaft power to electrical power. This arrangement was conventional, and electric utility operations and maintenance staff are familiar with synchronous machine operation. The cost of energy was minimized by operating the synchronous generator through a two-speed gearbox. Torsional dynamics were controlled by springs and dampers in the gearbox. Generating subsystems with variable speed capability were investigated and evaluated during the early MOD-5A design phase. These studies indicated that variable speed had a 5% higher cost of energy, because the equipment cost was greater.

Later, to reduce risks, the system was changed to a variable speed generating subsystem. It was found desirable to minimize the gearbox complexity and to provide a drivetrain back-torque during controlled shutdowns to reduce blade shutdown loads. A variable speed subsystem also assists the aerodynamic aileron control during the start-up by motoring the blades.

The requirements for the subsystem were to:

1. reduce the complexity of the gearbox, by providing drivetrain stiffness and damping control,
2. reduce aerodynamic shutdown loads by providing drivetrain back-torque, down to 12 rpm,
3. motor the high inertia rotor to above 3 rpm, to assist starting,
4. improve energy capture by changing speed ranges while delivering power,
5. operate over a range from 67% to 100% of maximum speed while generating (system frequencies prevented the use of larger range).

6. regulate airgap torque in response to a system reference, to control system speed and drivetrain dynamics, and to limit maximum torque,

7. regulate reactive power or voltage.

8.1.1 SUBSYSTEM EVALUATION

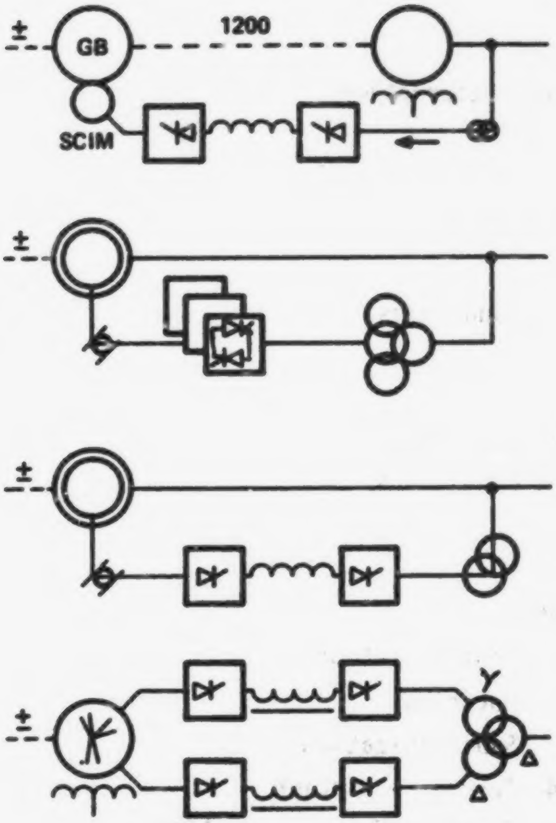
The four methods shown in Figure 8-1 were initially considered to provide variable speed capability. The mechanical Scherbius system would drive the ring gear of a planetary gear stage using an induction motor, variable speed drive. The static Kramer system is limited to speeds above the synchronous speed of the machinery and, therefore, requires a higher rated overspeed and higher converter power for the speed range. A study of ac drive technology (reference 1), was reviewed and applications of variable speed to wind generation (references 2 through 5) were considered. Either a static Scherbius (Scherbiustat) or a Load Commutated Inverter (LCI) drive system, operated as a generator, would meet the system requirements, so these systems were studied further.

A variable speed subsystem specification was prepared and quotations were obtained to assist in the evaluation. The specification's functional topics are shown in Table 8-1.

Both the LCI and the Scherbiustat arrangements met the system requirements. The GE LCI has an advanced digital control design and a market position in drive applications. The Scherbiustat offers a lower recurring cost because of a lower converter rating. Utility interface compatibility and preferences are still open issues. A Scherbiustat variable speed subsystem was selected for the MOD-5A model 304.2 design, because it had the lowest subsystem cost.

8.1.1.1 LCI Configuration

The main LCI configuration used in the evaluation was based on a 10,000 hp drive, made by GE's Drive Systems Department. The arrangement is shown in Figure 8-2. The major components of the LCI are a 4160 V, salient pole machine and a dual channel rectifier-inverter. The arrangement, described in reference 6, is capable of continuous variation in speed, from zero to maximum speed. A digital control is used and fault recovery logic is implemented in the converter firing control. Reactive power or voltage control is not used



MECHANICAL SCHERBIUS SYSTEM
AUXILIARY GEAR DRIVE/1.2 MVA/CCI/SCIM
7.5 MVA SYNCHRONOUS
0-15%, 85-115% OF SYNCHRONOUS SPEED

STATIC SCHERBIUS SYSTEM
6.3 MVA 6-8 POLE WRIM (STATOR)/1.5 MVA (ROTOR)
1.5 MVA 6 PULSE CYCLOCONVERTER ON GROUND
0-20%, 80-120% OF SYNCHRONOUS SPEED

STATIC KRAMER SYSTEM
5.0 MVA 8 POLE WRIM (STATOR)/3.0 MVA (ROTOR)
3.0 MVA 6 PULSE LCI CONVERTER ON GROUND
100-140% OF SYNCHRONOUS SPEED

LCI SYSTEM
7.5 MVA 6 POLE SYNCHRONOUS/DOUBLE WINDING
7.5 MVA 12 PULSE LCI CONVERTER ON GROUND
0-105% OF SYNCHRONOUS SPEED

Figure 8-1 Variable Speed Configurations

Table 8-1 Variable Speed Subsystem Requirements

- 3.1 Subsystem Definition
  - 3.1.1 General Description
  - 3.1.2 Subsystem Configuration
  - 3.1.3 Interface Definition
    - 3.1.3.1 Generator Mechanical Interfaces
    - 3.1.3.2 Generator Electrical Interfaces
    - 3.1.3.3 Converter Mechanical Interfaces
    - 3.1.3.4 Converter Electrical Interfaces
  - 3.1.4 Operational Description
    - 3.1.4.1 Duty Cycle Description
    - 3.1.4.2 Operational Power - Power Description
- 3.2 Characteristics
  - 3.2.1 Generator
    - 3.2.1.1 Generator Characteristics
    - 3.2.1.2 Generator Parameters
    - 3.2.1.3 Generator Environmental Conditions
  - 3.2.2 Converter
    - 3.2.2.1 Characteristics
    - 3.2.2.2 Converter Parameters
    - 3.2.2.3 Converter Environmental Conditions
    - 3.2.2.4 Converter Control
      - 3.2.2.4.1 General
      - 3.2.2.4.2 Control Modes
        - 3.2.2.4.2.1 Initialization
        - 3.2.2.4.2.2 Motoring
        - 3.2.2.4.2.3 Synchronization
        - 3.2.2.4.2.4 Torque Regulation
        - 3.2.2.4.2.5 Reactive Power Regulation
        - 3.2.2.4.2.6 Shutdown
        - 3.2.2.4.2.7 Fault Monitoring

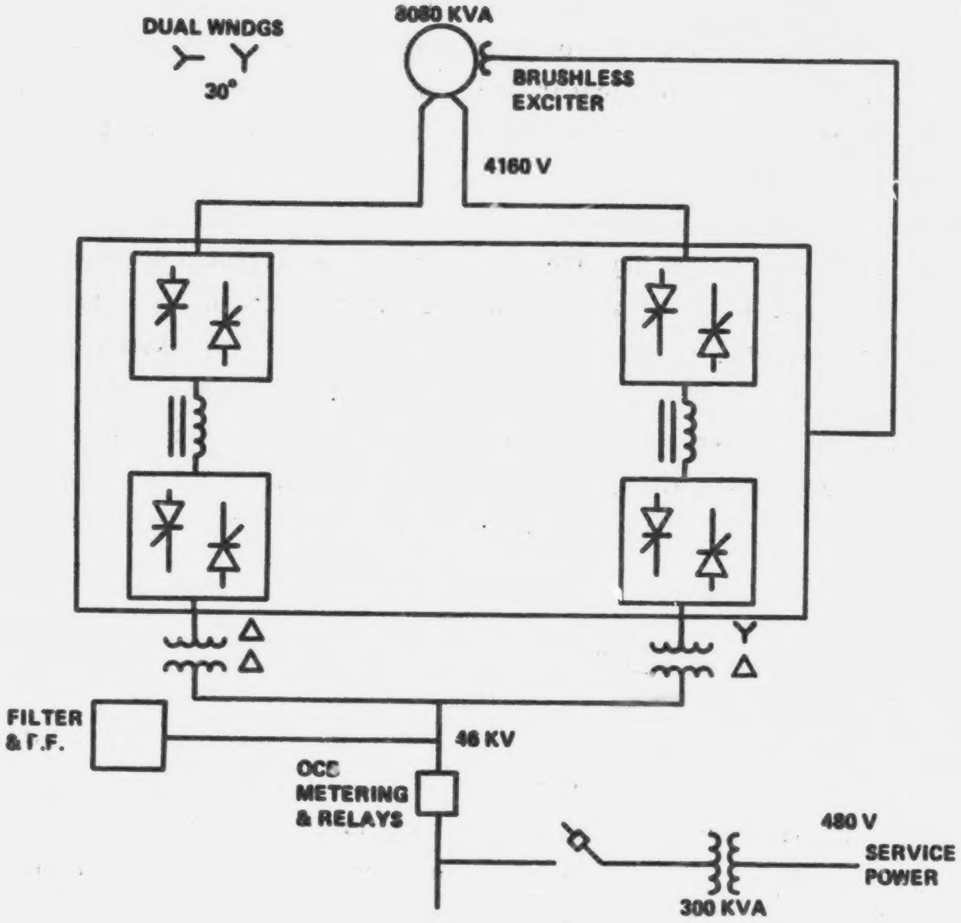

DUAL WNDGS
30°
8080 KVA
BRUSHLESS EXCITER
4160 V
Δ Δ
Y Δ
FILTER & P.F.
46 KV
OCC METERING & RELAYS
480 V
SERVICE POWER
300 KVA

Figure 8-2 LCI Subsystem Arrangement

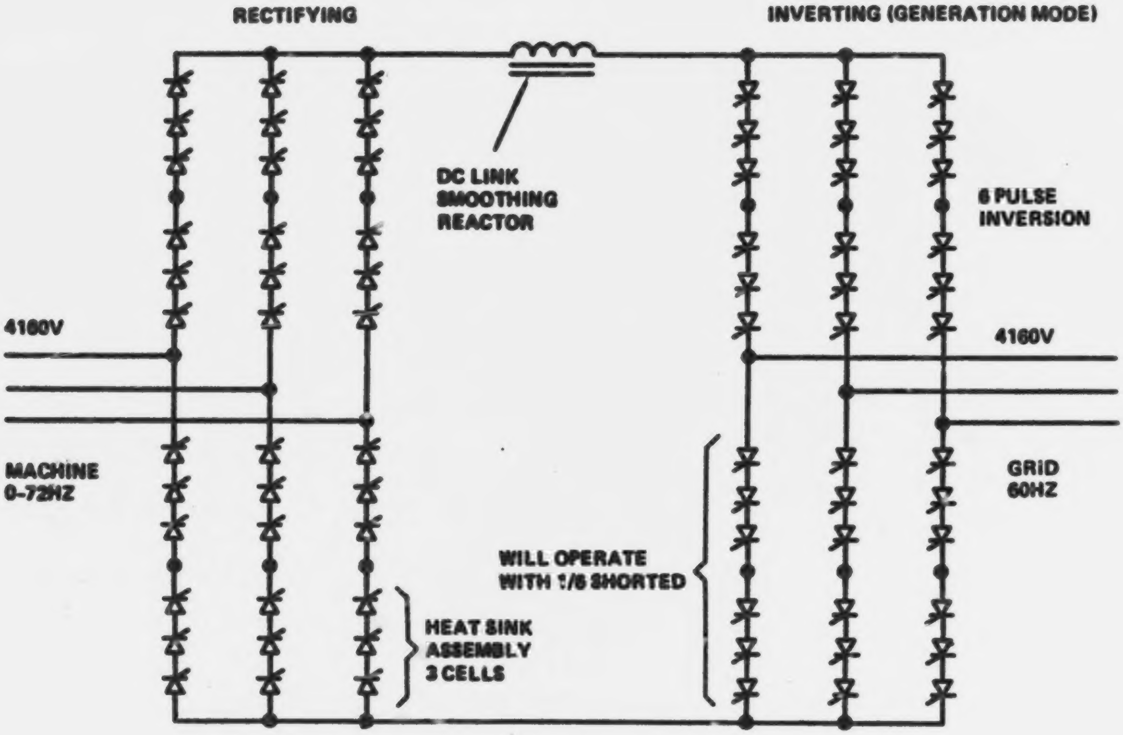
for drive applications. The implementation of this type of control would require a small modification of the standard control.

Each channel of the converter is a half-rated, 6-pulse, bidirectional rectifier-inverter. Dual machine windings and transformer connections provide the equivalent of 12-pulse performance with respect to harmonics. A wound stator-type, brushless exciter on the machine provides zero speed field control. The cells of each channel are shown in Figure 8-3 with some of the system features. Each bridge leg has six cells, but can operate with five cells, so one shorted cell does not force an outage. The use of a costly 4 kV fuse is avoided by providing sufficient leg impedance to limit fault currents to reasonable levels until the main circuit breaker operates to clear the fault.

Primary protection and switching are provided by a utility voltage level circuit breaker. Harmonic filters and power factor correction capacitance are also provided at the utility voltage. The capacitance compensates for the inverter stage reactive power demand. The control of the inverter firing angle permits operation over the full power range with a utility power factor near 1.0. In the generating mode, the converter operates as a line commutated device. When motoring for start-up, the machine "load" provides commutation with field control.

8.1.1.2 Scherbiustat Configuration

The Scherbiustat circuit is shown in Figure 8-4. This figure also shows the protective relay functions and a simplified one-line diagram of the Hawaiian Electric Company (HECO) distribution system at Kahuku, Oahu, where the first MOD-5A installation was planned. The arrangement is similar to GE's 15,000 hp drive used on the pulse power generator in Princeton, N.J., described in reference 7. A Canadian GE unit was evaluated. A wound rotor or doubly-fed machine is connected to the grid directly at the stator and through a cycloconverter at the rotor. Cycloconverters were used in other applications for full power speed control, as described in reference 8. The Scherbiustat arrangement is an active research topic for wind turbines and other applications.


RECTIFYING
INVERTING (GENERATION MODE)
DC LINK
SMOOTHING
REACTOR
6 PULSE
INVERSION
4160V
4160V
MACHINE
0-72HZ
GRID
60HZ
WILL OPERATE
WITH 1/6 SHORTED
HEAT SINK
ASSEMBLY
3 CELLS

CONVERTER 4040 KVA (HALF OF LCI CONFIGURATION)

SHOWN: 24 HEAT SINK ASSEMBLIES, 72 CELLS
TOTAL SYSTEM: 48 HEAT SINK ASMS., 144 CELLS
FULL CONVERTER & REACTORS: 50' LONG x 5' DEEP x 7-1/2' HIGH; 20,000# APPROX
REF: GEA 10816

Figure 8-3 LCI Converter Detail

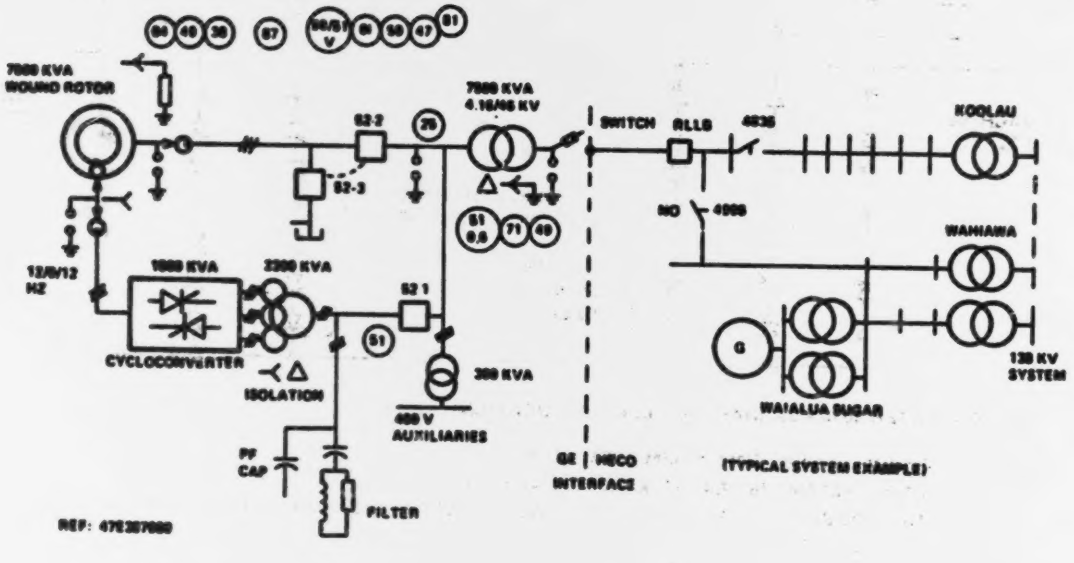

94
49
38
87
50/51 V
50
47
81
7000 KVA WOUND ROTOR
52-2
25
7000 KVA 4.16/46 KV
52-3
51 G,S
71
49
12/0/12 HZ
1000 KVA
2200 KVA
52 1
51
CYCLOCONVERTER
ISOLATION
300 KVA
480 V AUXILIARIES
PF CAP
FILTER
REF: 47E387080
SWITCH
RLLB
4636
NO
4999
KOOLAU
WAHIAWA
G
WAIALUA SUGAR
138 KV SYSTEM
GE | HECO INTERFACE
(TYPICAL SYSTEM EXAMPLE)

Figure 8-4 Scherbiustat Subsystem Arrangement

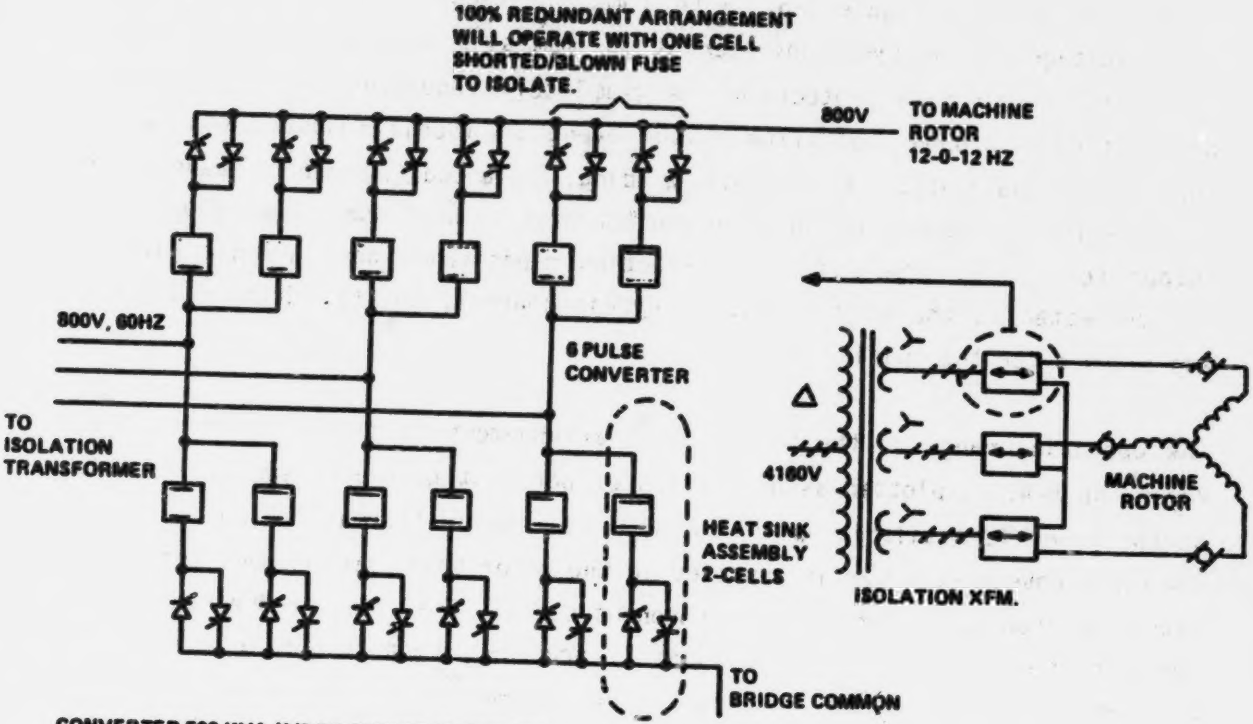
Three 4 kV circuit breakers protect the cycloconverter (52-1), connect the stator to the grid (52-2), and short-circuit the stator for starting (52-3). The cycloconverter rating, 1500 kVA, provides for generator operation from 12 rpm to 17.5 rpm at the wind rotor and for motoring to 3+ rpm.

The cycloconverter is arranged as three standard, 6-pulse, reversing dc drives, as shown in Figure 8-5. With a machine turns ratio of near 1:1, the input voltage to the cycloconverter at maximum slip permits use of a single series cell with fuse protection. A completely redundant cell arrangement provides ride-through capability in the event of a cell failure, similar to the LCI's capability. A multiple winding, balanced impedance transformer isolates the cycloconverter bridges and operates to both sum and step-up their output to 4160 V. Power factor correction capacitance and harmonic filters are connected at the 4160 V bus. A hybrid control, the GE Directomatic II, was planned for the initial unit.

The operating range of the Scherbiustat arrangement is shown in Figure 8-6. Power, in MVA, is plotted as a function of per unit generator speed. Machine stator power is available up to the 6500 kVA stator thermal rating. Through the cycloconverter, power is supplied to the rotor below synchronous speed and extracted from the rotor above synchronous speed. The wind turbine controller commands the cycloconverter controller to produce airgap torque in proportion to speed error, as shown in Figure 8-6. Depending on the wind speed, as measured by the average power output, the controller uses either a low speed reference of 0.9 per unit synchronous speed, or a high speed reference of 1.1 per unit speed. The control characteristic would be the same for either a Scherbiustat or an LCI variable speed subsystem.

8.1.1.3 Comparison

The performance of the two subsystems were compared and relative weight factors were applied to the comparison of criteria, as shown in Table 8-2. The performance of the prototype and the product's maturity were emphasized. The cost and performance comparisons were made at the subsystem level, including utility voltage step-up level, the housing of converter equipment, cable sizes, switchgear, and annual maintenance. For example, the time and cost for periodically cleaning the brush rigging compartment and replacing


100% REDUNDANT ARRANGEMENT
WILL OPERATE WITH ONE CELL
SHORTED/BLOWN FUSE
TO ISOLATE.
800V
TO MACHINE
ROTOR
12-0-12 HZ
800V, 60HZ
6 PULSE
CONVERTER
TO
ISOLATION
TRANSFORMER
Δ
4160V
MACHINE
ROTOR
HEAT SINK
ASSEMBLY
2-CELLS
ISOLATION XFM.
TO
BRIDGE COMMON

CONVERTER 500 KVA (1/3 OF CYCLOCONVERTER)
CIRCUIT IS STANDARD REVERSING D.C. DRIVE ARRANGEMENT
SHOWN: 6 HEAT SINKS x 2 CELLS x 2 REDUNDANT = 12 HEAT SINKS, 24 CELLS
TOTAL SYSTEM: 36 HEAT SINK ASMS, 72 CELLS
CONVERTER & CONTROL: 18' LONG, 7' DEEP, 7-1/2' HIGH; 11,000# APPROX.
ISOLATION TRANSFORMER: 5-1/2' LONG, 5' DEEP, 8-1/2' HIGH; 12,000# APPROX.

Figure 8-5 Scherbiustat Converter Detail

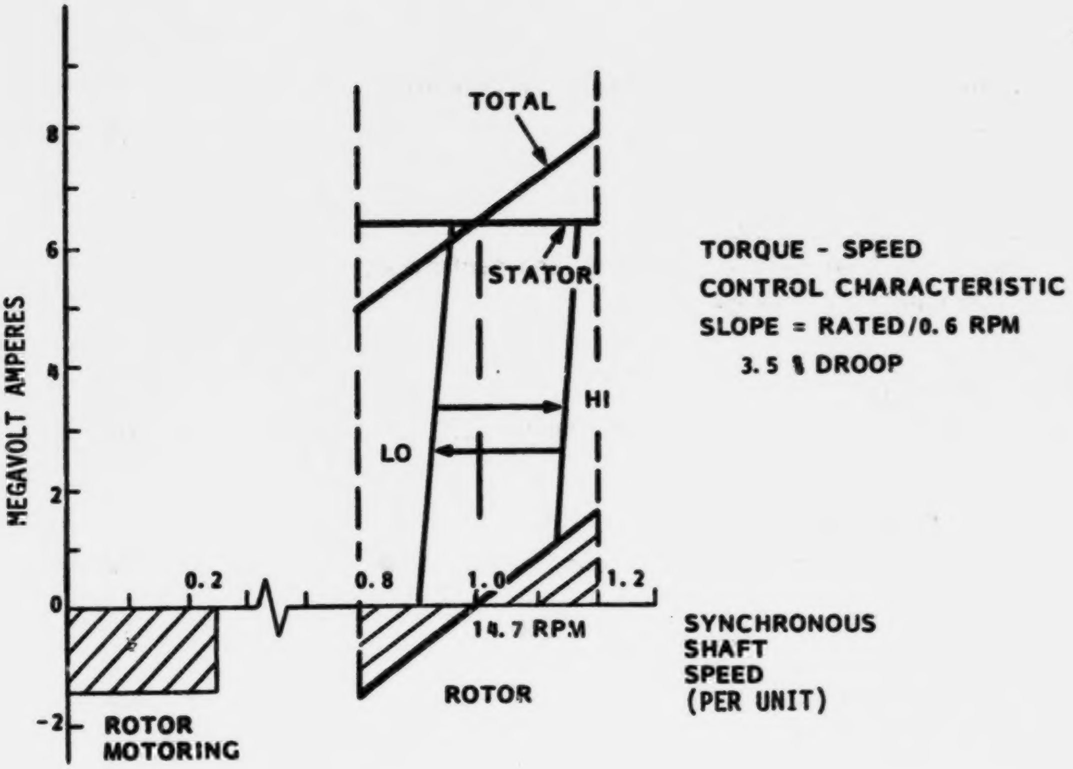


Figure 8-6 Generator Operating Regime

Table 8-2 Evaluation Criteria and Weight

CRITERION	WEIGHING
Compatibility - With Wind Turbine application and control system.	20%
Quality of Power Output - Risk or degree of margin in meeting power quality requirements.	15%
Reliability - Potential impact on WTG availability including effect of single failure modes.	15%
Product Maturity/Prototype Risk - Confidence that system will work and perform as advertised on Prototype.	15%
Maintainability - Ease of maintenance and trouble shooting.	10%
Customer Technology Acceptance - Preferences/biases of utility customers.	10%
Life - Probability of 30 year life.	10%
Schedule - Prototype delivery schedule.	5%
	100%

brushes was included in the cost of the Scherbiustat arrangement. An electrical comparison is shown in Table 8-3. This comparison ranks the two configurations very closely.

Harmonic content is an issue for the acceptance by the utility of static power converters, as used in both arrangements. IEEE Guide 519 (reference 9) is generally used to establish harmonic control and reactive compensation levels, subject to the utility's requirements. These guidelines, along with the conditions GE and HECO planned, are shown in section 8.9.

Because the LCI produces 12-pulse harmonic currents and is effectively dc fed, the filtering design necessary to provide a smooth output is not complex. However, the filters do have to contend with full power harmonic amplitudes. The Scherbiustat, with a 6-pulse cycloconverter, produces more complex harmonics with a high amplitude. They vary with slip frequency, but with only 20% of the system output. A complete harmonic analysis specific to the site was planned for the MOD-5A.

The evaluation determined that both subsystems met the requirements. The LCI had more flexibility and was rated above the Scherbiustat, but it cost more for initial and volume production wind turbines. A Scherbiustat configuration was, therefore, selected for the MOD-5A. The utility's preference was under evaluation.

8.1.2 PERFORMANCE

The expected performance and controls analysis is described in volume II, section 6.5. The results are summarized in this section to illustrate the power fluctuations that result from wind turbulence and gusts.

A simulation of the MOD-5A is shown in Figure 8-7. The important drivetrain and tower bending modes are included. Both simple and complex converter and generator models were developed. The simple model does not include the electrical dynamics. The complex model includes the electrical dynamics and permits analysis of the quadrature real and reactive power regulator circuits that drive the cycloconverter firing control. The generator inertia was changed to an equivalent value in the wind rotor speed reference, and

Table 8-3 Evaluation Comparison

COMPARISON OF LCI/SYNCHRONOUS MACHINE
WITH CYCLOCONVERTER/WOUND ROTOR INDUCTION MACHINE
(1 = POOR, 3 = AVERAGE, 5 = OUTSTANDING)

	(1) CYCLO/INDUC.	(2) LCI/SYNCH.	COMMENT
PERFORMANCE UNDER SINGLE PHASE FAULTS	3	5	1
PERFORMANCE UNDER THREE PHASE FAULTS	5	5	2
PERFORMANCE UNDER LINE SURGES	5	3	3
CONTROL RESPONSE	5	3	4
STARTING PERFORMANCE AS MOTOR	4	3	5
POWER FACTOR CONTROL	5	4	6
TORQUE HARMONICS DURING RUNNING	3	4	7
TORQUE HARMONICS DURING STARTING	4	3	7
HARMONIC FILTER REQUIREMENTS	3	4	8
MAINTENANCE	4	5	9
CIRCUIT COMPLEXITY	3	3	
	44	42	

COMMENTS:

1. COULD RESULT IN DE-EXCITATION OF MACHINE IN (1).

2. BOTH CAN PROVIDE RAPID RECLOSE AFTER THREE PHASE FAULT.

3. LINE SURGES COULD RESULT IN COMMUTATION FAILURES IN (2). CYCLE IS BUFFERED BY AN EXTRA TRANSFORMER.

4. CURRENT IN DAMPER WINDINGS IN (2) OPPOSE RAPID CHANGES IN TORQUE WITHOUT MORE ELABORATE CONTROL SCHEMES (FIELD ORIENTED CONTROL).

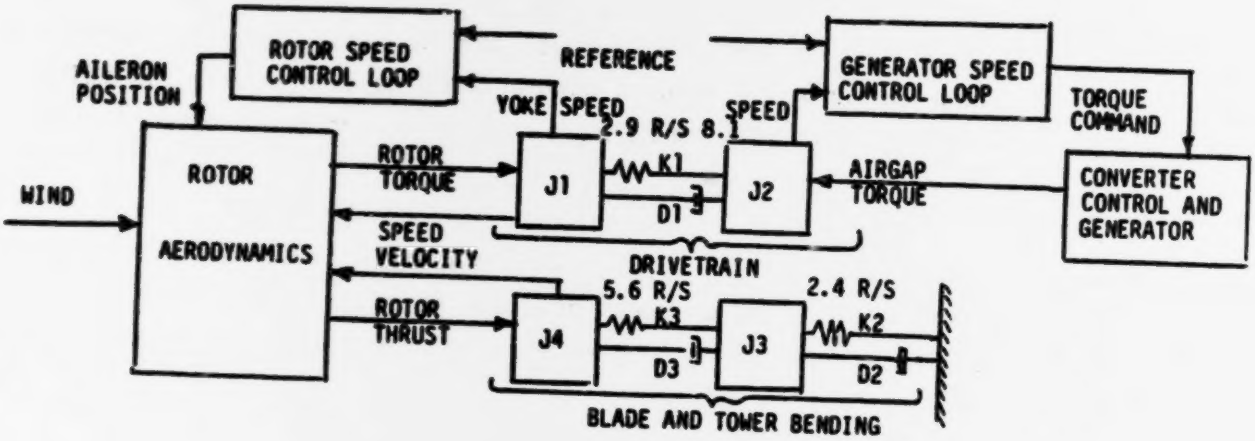
5. HIGHER STARTING TORQUE AVAILABLE FROM CYCLE WHEN CONNECTED TO THE STATOR OF THE MACHINE FOR STARTING. WHEN USING (1) AVAILABLE STARTING TORQUE IS PROPORTIONAL TO CYCLOCONVERTER RATING, USING (2) IT DEPENDS UPON SIZE OF LINK INDUCTOR AND LIMITED TYPICALLY TO A SMALL FRACTION OF RATED TORQUE (ABOUT 0.1 PU).

6. POWER FACTOR CONTROL IS INHERENT IN THE CONTROL OF THE CYCLO. POWER FACTOR CONTROL WITH (2) COMES WITH CAREFUL PHASE SHIFTING OF THE UTILITY SIDE BRIDGE IN CONJUNCTION WITH A BANK OF CAPACITORS.

7. TORQUE HARMONICS OF (1) ARE MORE SEVERE DURING RUNNING IN THAT THEY TEND TO BE MORE RANDOM AND THEREFORE LESS PREDICTABLE. TORQUE HARMONICS OF (2) ARE MORE SEVERE DURING STARTING DUE TO THE MODULATION OF THE DC LINK CURRENT TO ACHIEVE COMMUTATION OF THE MACHINE SIDE BRIDGE AT LOW ROTATIONAL SPEED.

8. HARMONIC FILTERING IS MORE DIFFICULT WITH (1) DUE TO THE MORE RANDOM NATURE OF THE HARMONICS.

9. MAINTENANCE IS A SMALL BUT NOTEWORTHY PROBLEM WITH (1).


ROTOR SPEED CONTROL LOOP
REFERENCE
GENERATOR SPEED CONTROL LOOP
AILERON POSITION
YOKE SPEED
SPEED
TORQUE COMMAND
2.9 R/S 8.1
ROTOR
WIND
ROTOR TORQUE
J1
K1
J2
AIRGAP TORQUE
CONVERTER CONTROL AND GENERATOR
D1
AERODYNAMICS
SPEED VELOCITY
DRIVETRAIN
5.6 R/S
2.4 R/S
ROTOR THRUST
J4
K3
J3
K2
D3
D2
BLADE AND TOWER BENDING

J1 = ROTOR INERTIA	$40 * 10^{6}$ SLUG-FT^{2}
J2 = GENERATOR & HIGH SPEED SHAFT INERTIA REFLECTED TO ROTOR	$(745+30)(82.14)^{2} = 5.2*10^{6}$ SLUG-FT^{2}
J3 = TOWER MASS	$2.9 * 10^{4}$ SLUG
J4 = BLADE FLAP MASS	$1.06 * 10^{3}$ SLUG
K1 = DRIVETRAIN SPRING CONSTANT	$3.38 * 10^{8}$ FT-LB/RAD
K2 = TOWER SPRING CONSTANT	$1.374 * 10^{5}$ LBS/FT
K3 = BLADE FLAP SPRING CONSTANT	$3.370 * 10^{4}$ LBS/FT
D1 = DRIVETRAIN DAMPING COEFFICIENT	$3.0 * 10^{6}$ FT-LB/(RAD/SEC)
D2 = TOWER DAMPING COEFFICIENT	6960 LBS/(FT/SEC)
D3 = BLADE FLAP DAMPING COEFFICIENT	3785 LBS/(FT/SEC)

Figure 8-7 Simulation Model Block Diagram

generator speed is thus shown as the actual generator speed divided by the gearbox ratio of 82.14.

The gust performance of the simplified model is illustrated in Figure 8-8. The basic gust is 9 mph, with a 12 second period and a sinusoidal shape departing from an average 45 mph wind. A turbulent harmonic wind is added in Figure 8-9, in accordance with NASA's interim turbulence definition. Trade winds are not expected to be as turbulent as they are in the NASA definition.

The generator torque level is clamped at just above rating by the control logic, as shown in Figure 8-8, set b. Total output increases slightly above the clamp plateau as the generator speed increases. The aileron aerodynamic control slowly operates to reduce the gust torque. The gust ends and the system speed and power slightly undershoot the initial conditions with a smooth, well-behaved return in about a minute. The gust is modeled as fully immersing the rotor, which is a more severe condition than could occur in the field.

The effect of wind turbulence is shown in Figure 8-9. A steady oscillation of system speed and output power of about 10% peak to peak is predicted. This oscillation could be reduced by decreasing the slope of the speed-torque control characteristic.

8.1.3 DESIGN CRITERIA

The variable speed subsystem, comprised of a wound rotor generator, cycloconverter, isolation transformer, and converter control were functionally defined in GE Specification 47A380094. The converter control is responsible for closed loop control of airgap torque and reactive power by quadrature firing control of the cycloconverter thyristors. The converter control requirements are described in section 9.1.5.

Other elements of the power generation subsystem design criteria were defined by specifications. Vendor's standard equipment was preferred, while modifications necessary to meet the requirements were minimized. Equipment with a history of reliable operation and low maintenance was preferred. Mean time between failures and mean time to repair were selectively specified.

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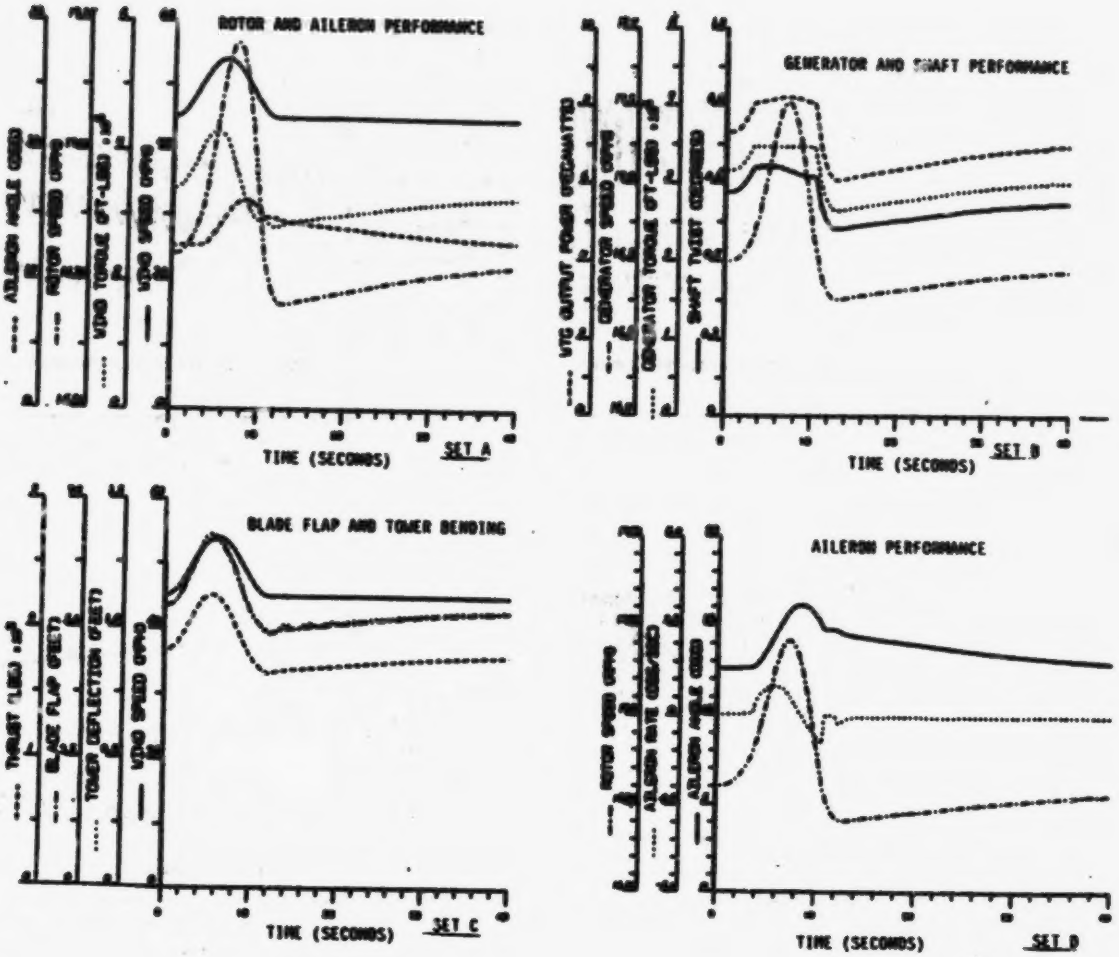

Figure 8-8 Response to 1-Cosine Wind Change

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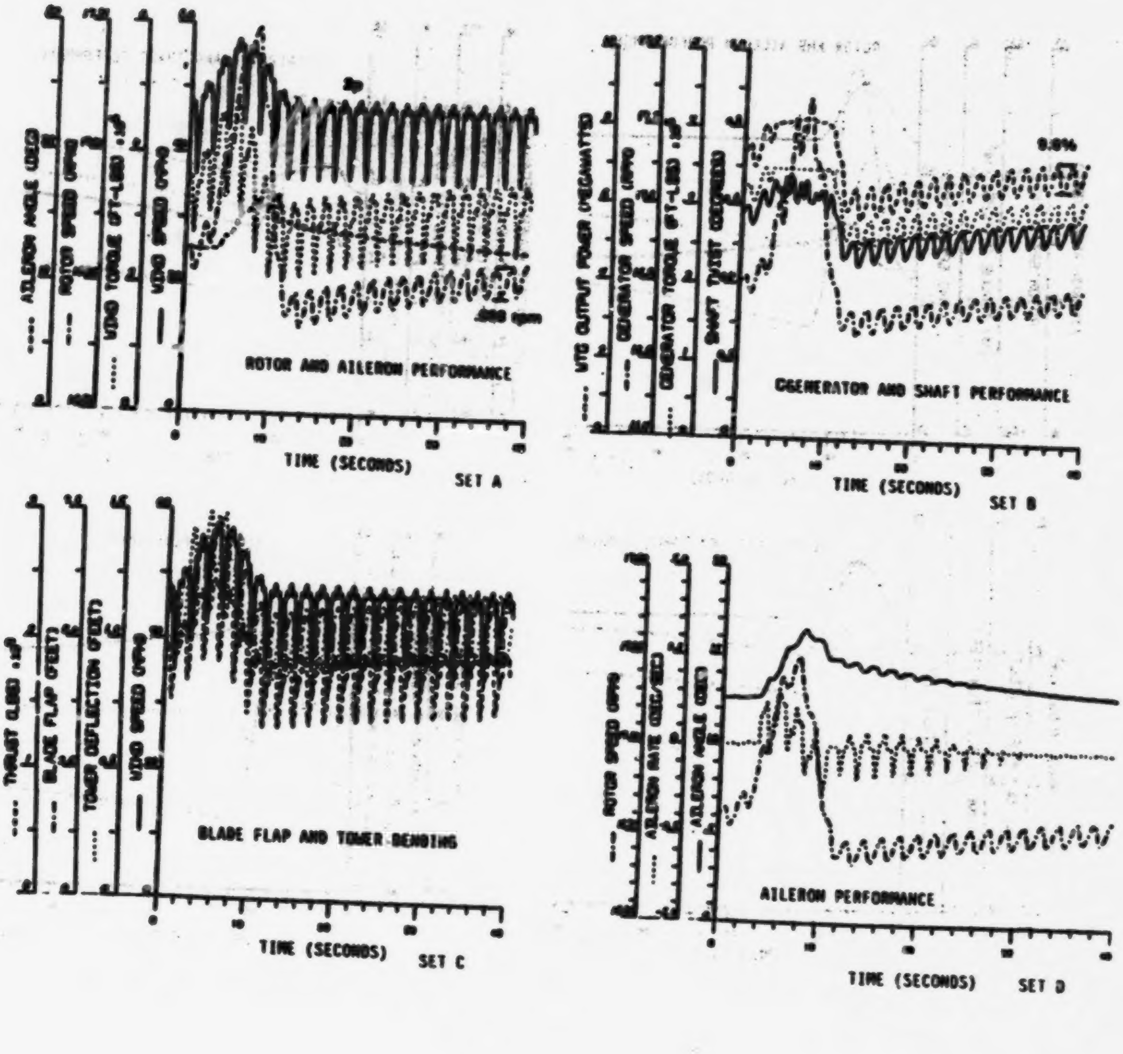


Figure 8-9 Response to Wind Change with Turbulence

8.2 POWER GENERATION SUBSYSTEM DESCRIPTION

The major components of the power generation subsystem are the:

- generator
- converter
- yaw slipring assembly
- cabling
- switch gear
- step up transformer
- harmonic filter
- electrical service
- station battery/UPS

The location of these components is shown in Figure 8-10. A simplified, one-line diagram of the power generation subsystem is shown in Figure 8-11.

The generator is a 7500 kVA, wound rotor, 6-pole machine, with a 6300 kVA stator, 1500/0/1500 kVA rotor. The stator output frequency is maintained at 60 Hz by a static converter and its associated controls. The stator and converter output is 4160 V. While singly excited, the generator provides motoring duty between 0 and 300 rpm to rotate the blades.

The converter controls the generator air gap torque and reactive power. The converter and its controls are located in an enclosure near the base of the tower. Output power, service power, control signals, and data are transmitted between the rotatable nacelle and the stationary tower by the yaw slipring assembly. Switchgear for the stator short, stator tie, converter tie and associated relays are located in the enclosure with the converter.

The step-up transformer is the interface between the generator and converter and the utility interconnect. Filters suppress the harmonic currents produced by the converter.

The electric service provides the power for lighting, heating, cooling, hydraulic supply, lubrication, and miscellaneous services.

The station battery provides the power for operation of the electrical switch gear. The uninterruptible power supply provides power for the instrumentation and controls when utility power is interrupted, to facilitate shutdown and enable the wind turbine to start and continue operation when the utility power is restored.

MAJOR SUBASSEMBLIES

- GENERATOR
- YAW SLIP RING ASSEMBLY
- POWER CABLING
- CONVERTER
- SWITCHGEAR
- STEP-UP TRANSFORMER
- STATION BATTERIES

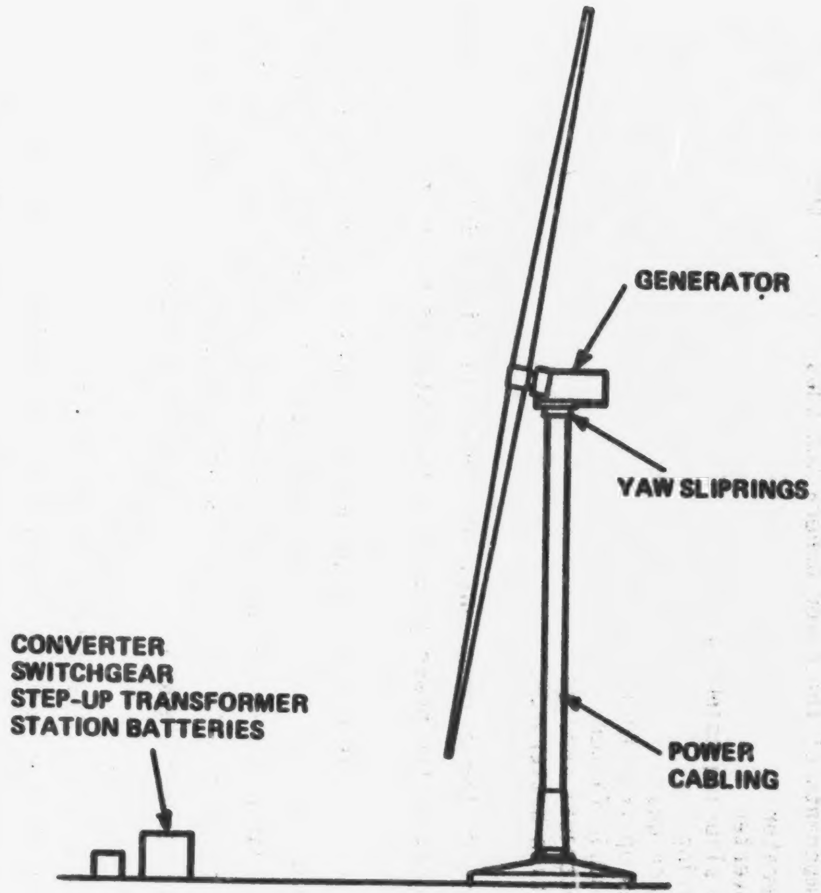

GENERATOR
YAW SLIPRINGS
POWER CABLING
CONVERTER
SWITCHGEAR
STEP-UP TRANSFORMER
STATION BATTERIES

Figure 8-10 Power Generation Subsystem Components

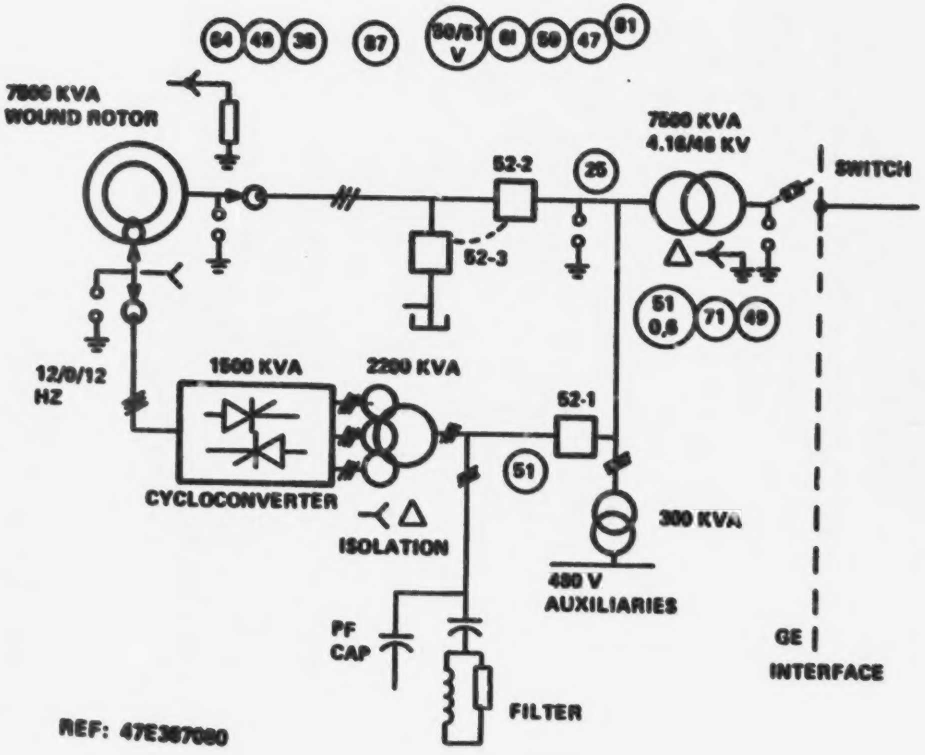

64
49
38
87
50/51 V
81
59
47
81
7500 KVA
WOUND ROTOR
52-2
25
7500 KVA
4.16/46 KV
SWITCH
52-3
51 0,6
71
49
12/0/12
HZ
1500 KVA
2200 KVA
52-1
51
CYCLOCONVERTER
ISOLATION
300 KVA
480 V
AUXILIARIES
PF
CAP
FILTER
GE
INTERFACE
REF: 47E367080

Figure 8-11 Power Generation One-Line Diagram

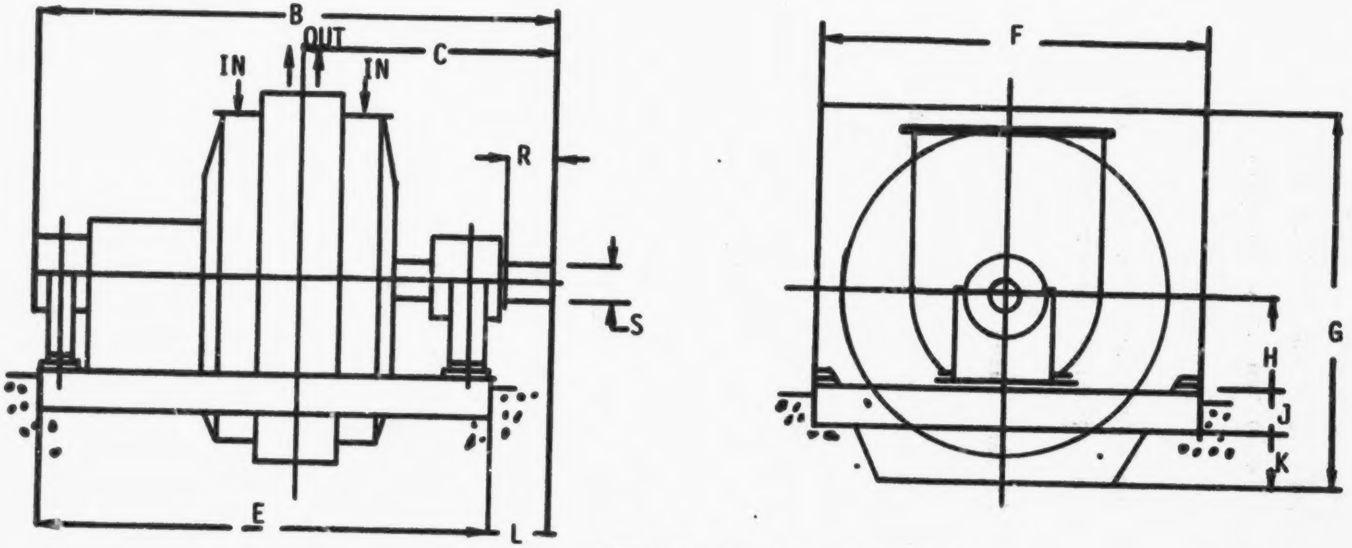
8.3 GENERATOR

The generator requirements are listed in Table 8-4.

Table 8-4 Generator Requirements

PARAMETER	REQUIREMENT
Power	5000 kW at 960 rpm/7500 kW at 1440 rpm
Air Gap Torque	38,500 ft.-lb.
Mounting	7° inclination
Bearings	self-lubricating journal bearings with provision for external flood lubrication
Motoring Speed Range	0 to 300 rpm
Generating Speed Range	960 to 1440 rpm
Mechanical Overspeed Rating	1700 rpm
Phases	3
Frequency	60 Hz
Voltage	4160 V_{L-L} external wye
Temperature Rise	105°C rise above 40°C ambient
Insulation	Class F
Losses (Maximum)	100 kW at no load/300 kW at full load
Operating Temperature	-20° to +40°C
Non-operating Temperature	-40° to +50°C
Elevation	3300 ft/7000 ft. with derating

The dimensions of the generator are shown in Figure 8-12. The accessories supplied with the generator are listed in Table 8-5.



TOTAL WEIGHT - 48,000 lbs.

CLASSIFICATION						APPROXIMATE DIMENSIONS IN INCHES																
TYPE	POLES	HP	FL/RPM	VOLTS	S.F.	A	B	C	D	E	F	G	H	J	K	L	M	N	P	R	S	U
M	6	8700	1193	4000	1.0		147.2	69.2		128	100	88	21	11.5	11.5	14.7					12.2	8.5

Figure 8-12 Generator Outline

Table 8-5 Generator Accessories

ITEM	DESCRIPTION
Flood Lubrication System	Reservoir, reservoir heaters, filter, pump, pump motor, starter, sensors, hydraulic interconnections and electrical interconnections supplied in a separately mounted package
Stator and Rotor Connection Boxes	Each box contained surge capacitors and surge arrestors for lightning protection
Stator RTDs*	Six each (2 per phase), 10 ohm copper RTDs
Bearing RTDs	Two each (one per bearing), 10 ohm copper RTDs
Pulse Generator	Avtron M-378-A-ID-240 with dual isolated outputs, 240 pulses per revolution
Space Heater	208 V, 3 phase, 4 wire, 60 Hz, 3kW (maximum) for continuous energization
Vibration Sensor	One per bearing
Connection Boxes	Separate connection boxes are provided for heater and instrumentation connection

* (RTD=Resistance Temperature Detector)

Switch sensors are located to monitor the generator bearing temperature, bearing vibration and stator temperature. These sensors signal the control system in the nacelle by opening the sensor contact if any of the sensed values exceed design limits. If the control system receives this signal, it stops the wind turbine in an orderly shutdown procedure.

A transformer and high current resistor provided the neutral ground connection. This arrangement was designed to limit ground fault currents to less than 10 A and provides a simple way to detect ground faults, by sensing resistor voltage.

The instrument current transformers for differential current detection were mounted at the generator neutral connection.

The manufacturer will perform the following development and production tests on the generator:

High potential test
Insulation resistance test
Rotor balance
No-load loss measurement (motor conditions)
Phase sequence
Connection continuity, conformance to diagram
Dimensional check, conformance to installation drawings
Visual check for finish defects
Segregated loss test for core loss, windage and friction, stray load
Heat run in motor mode, with rings shorted (to the limit of test facility)
1/4 voltage single phase impedance check
Open circuit secondary voltage
No-load speed, rings shorted
Shaft voltage and current
Air-flow
Noise
Bearing operation at 7° inclination

As part of a sub-system test, the generator was also to be tested by the manufacturer for motoring, synchronizing, and generating at about 2800 kW.

8.4 CONVERTER

The static converter, or cycloconverter, provides frequency conversion, airgap torque regulation and reactive power regulation control for the variable speed generator under the direction of the system controller. The indoor unit weighs 9200 lbs, is 184 in. long, 90 in. high, 84 in. deep. The converter has the characteristics listed in Table 8-6.

Table 8-6 Cycloconverter Characteristics

Type	Thyristor, 3 Phase, 6 pulse per phase, reversing
Rating	1500 kVA
Machine Connection	Coordinated with generator rotor characteristics
Line Connection	Through isolation transformer to 4160 volt L-L, 60 Hz, 3 Phase
Enclosure	Indoor NEMA 1 type with front door access to all electronic components, and rear panel access to connections.
Frequency	Line connection 60 Hz. Machine connection with real power capability proportional to frequency for 12/0/12 Hz operation.
Harmonics	Converter control and connection minimizes current harmonics on the 60 Hz system.
Reactive Power	Converter reactive power duty is minimized by use of 60 Hz system filter and power factor correction capacitance. System operation will be at 0.98 to 1.0 pf.
Overvoltage Protection	A machine side thyristor controlled resistive shunt protects the power circuitry from transient overvoltages.
Cooling	Dual fans circulates ambient air. Either fan is capable of cooling from rated conditions.
Fault Protection	Power modules are fused to prevent module permanent faults from propagating damage.

Table 8-6 Cycloconverter Characteristics (Cont'd)

Control	Basic control mode is independent control of machine air gap torque by stator power regulation and control of either 60 Hz bus reactive power or voltage.
Losses	No load, with control and fan loads, 10 kW maximum. Rated conditions, 25 kW maximum (converter only.)
Maintenance	Design is suitable for a six (6) month or more periodic inspection and maintenance interval. Control and power elements are of modular construction and replaceable from the front.
Diagnostics	Light emitting diode indicators and local logic devices are provided to aid in rapid fault diagnosis to maximize availability.
Reliability	Mean Time Between Failures Requiring Maintenance - 9,000 hours Mean Time to Repair - 2 hours (with spare parts)
Life	The expected design life is 30 years, with periodic maintenance.
Materials	Construction materials are inherently corrosion resistant or protected from corrosion caused by exposure to airborne moisture and salt in cooling air. Circuit boards are conformal coated where possible for general contamination protection.
Space Heater	An anti-condensation heater, suitable for continuous energization is mounted and wired in the bottom of each equipment section. 208 Vac, four wire, three phase, 60 Hz power at 2 kW maximum is provided for balanced load heater operation.
Grounding	A ground bus runs through all equipment sections and the connection is readily accessible.
Bus Work	Bus bar is of standard construction. Connections are immune to the effects of zero to full load cycling.
Electromagnetic Interface	The cycloconverter and its controller do not produce conducted or radiated signals that interfere with commercial electromagnetic devices. The converter and its controller do not malfunction when a portable communication device with a transmitter (up to 5 W) is operated within 10 ft of the closed cabinet doors.

Cycloconverter Environmental Conditions

The cycloconverter, and the isolation transformer through which it is connected to the 4160 V, 60 Hz bus, are housed in a building at grade level. The ambient temperatures during operation can range from 0°C to +40°C. The unit can survive in ambient temperatures between -40°C and +50°C if it is not operating. The relative humidity can range between 10% and 90%. The cooling air is mechanically filtered to remove airborne moisture, salt, and particulate matter, as described, in section 6.5.

The power and voltage ratings apply at altitudes between sea level and 3300 ft. The design may be used in altitudes of up to 7000 ft., and at higher ambient temperature ratings. In these applications the appropriate cooling and insulation ratings must be lowered.

Control Modes

The basic operating modes of the converter control are: initialization, motoring (singly excited machine), synchronization, torque regulation, reactive power regulation, shutdown, and fault monitoring. The converter has discrete and analog signal interchange between the wind turbine generator (WTG) controller switchgear transducers and the converter control. A description of the converter control sequence is in section 9.1.5.

8.5 SLIPRINGS

The slipring assemblies in the yaw and rotor areas transfer power, control signals and data between rotating and non-rotating sections.

Yaw Slipring Assembly

The yaw slipring assembly, shown in Figure 8-13, is located near the top of the tower beneath the nacelle, and transfers the generator stator and rotor power, the nacelle service power, control signals and data. The types and quantities of sliprings in the assembly are listed in Table 8-7.

Table 8-7 Yaw Slipring Assembly

		QUANTITY
High Voltage Rings	1500A, 5kV	7
Power Rings	300A, 600V	4
	50A, 600V	3
	30A, 600V	9
Control Rings	5A, 600V	37
Signal Rings	1A, 125V	92
Total Rings		152

Size: 138 in. high, 35 in. wide, 35 in. deep. Weight: 3500 lbs.

Characteristics

The rotor and stator structural members of the yaw slipring assembly are fabricated from aluminum alloys with cross sections thick enough to withstand anticipated loads. Kaydon Reali-Slim bearings with Teflon, grease, and moisture seals are used at the rotating interfaces. A combination of laminated glass (G-10) and mineral-filled epoxy is the insulating material for the slipring and brush block assemblies, with barriers to meet the insulation resistance and dielectric strength requirements. The ring surfaces have a high finish. The contacting brush force was calculated to meet the life requirements and to minimize dynamic noise.

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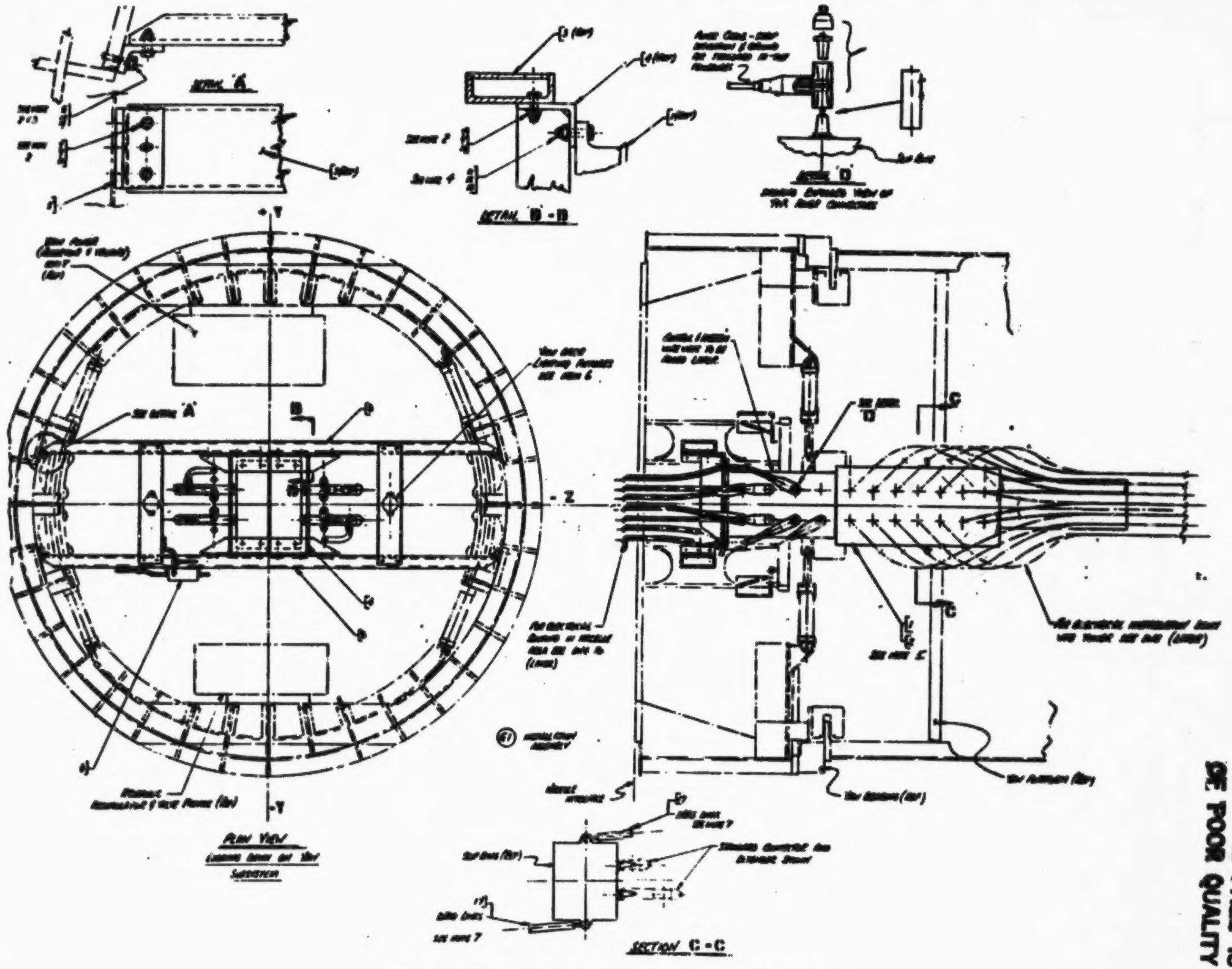
DETAIL 'A'
DETAIL 'B-B'
DETAIL 'D'
+Y
-Y
-Z
C
C
B
PLAN VIEW
SECTION C-C

Figure 8-13 Yaw Slip Ring Installation

High Voltage Circuits

Sliprings and brushes for the generator output power are rated at 1500A, and 5000V. The rings are pure copper with a hard silver wear surface contacted by twelve composition brushes for each circuit. "GlidCop" material provides a low resistance path for current through the cantilever brush springs. Copper shunt cables are used in parallel with the brush springs. The brush block terminal bars are pure copper. The smallest cross-sectional area of each 1500A circuit is 1000 MCM. A combination of G-10 and phenolic barriers is sandwiched between all brush and spring assemblies and terminal blocks. This combination maintains dielectric integrity between circuits.

As an extra precaution, grounded guard rings are installed between each phase of the high voltage slipring. In the event of an arc-over the guard ring will transfer the fault to ground through the rotor case and the ground connector. Phase to phase faults are avoided with this arrangement.

Intermediate Power Circuits

The sliprings and brushes for intermediate power circuits are rated at 300A, and 600V. Each ring is contacted by four composition brushes for each circuit. The smallest cross sectional area of each 300A circuit is 220 MCM. The materials and configurations of these rings and brushes are identical to those used in the high voltage circuits.

Low Power Circuits

The sliprings and brushes for low power circuits are rated at 50A or 30A, and 600V. Each ring is contacted by two composition brushes for each circuit. The smallest cross-sectional area of each 50A circuit is 70 MCM. The materials and configurations of these rings and brushes are identical to those used in the high voltage circuits.

Command and Control Circuits

The sliprings and brushes for command and control circuits are rated at 5A, and 600V. Each ring is contacted by two composition brushes for each circuit. The materials and configurations of these rings and brushes are identical to those used in the high voltage circuits, except that shunt cables are not necessary on the brush springs.

Signal Circuits

Sliprings and brushes for signal circuits are rated at 1A, and 125V. Each ring is contacted by two composition brushes for each circuit. The materials and configurations for these rings and brushes are identical to those used in the command and control circuits.

ELECTRICAL CONNECTIONS

Rotor Connections

The high voltage power rings terminate in high voltage bushings (Elastimold P/N 600S1), with two bushings per circuit. The guard ring between the high voltage circuits terminate at the rotor cap case or an external connection or both.

All other power circuits terminate in a completely enclosed terminal box. Each power circuit terminates in a feed-through screw clamp terminal block, at the sizes required to meet the current capacity and wire size of the circuits.

All signal circuits terminate in a completely enclosed terminal box positioned 180° from the power terminal box. Each signal circuit terminates in a feed-through screw clamp type terminal block, at the size required to meet the current capacity and wire size of the respective circuits.

Stator Connections

The high voltage power brush blocks terminate in high voltage bushings (Elastimold P/N 600S1), with two bushings per circuit.

Power, command, and control circuits terminate in individual brush blocks with screw terminations, to avoid crimping or soldering which might cause problems because of the large conductors.

All signal circuits terminate in brush blocks, with crimped terminal lugs and attached hardware.

Position Sensor

The position sensor is installed and wired by the slipring manufacturer. The sensor is mounted inside the rotor signal junction box by means of servo cleats, and is wired to an adjacent terminal board. The position sensor can be adjusted and replaced in the field by removing the gasketed signal junction box cover, and the protective cover inside the terminal box.

ROTOR SLIPRING ASSEMBLY

The rotor slipring assembly is mounted with brackets that are attached to the gearbox back wall. It is driven by a concentric conduit that penetrates the entire drivetrain from the slipring forward to the rotor. The slipring provides paths for power and signals from the nacelle to the rotating blades. The hydraulic pump requires power to run the aileron actuators. The signals command the aileron positions, read the aileron positions, control valves and receive feedback. The types and quantities of sliprings in the assembly are listed in Table 8-8.

Table 8-8 Rotor Slipring Assembly

TYPES OF RINGS	RATING	QUANTITY
Power Rings	80A, 600V	4
	25A, 600V	12
Control Rings	5A, 600V	39
Signal Rings	1A, 125V	45
Total Rings		100

Dimensions: 16 in. high, 54 in. long, 11 in. deep. Total Weight: 250 lbs.

Characteristics

The rotor and stator structural members are fabricated from aluminum alloys with cross-sections thick enough to withstand the anticipated loads. Kaydon Reali-Slim bearings with Teflon grease and moisture seals are used at the rotating interfaces. A combination of laminated glass (G-10) and mineral-filled epoxy is the insulating material for the slipring and brush block assemblies, with barriers to meet insulation resistance and dielectric strength requirements. The ring surfaces have a high finish. The contacting brush force was calculated to meet the life requirements and to minimize dynamic noise.

50 A Power Circuits

Sliprings and brushes for these circuits are rated at 80A and 600V. They supply power to the hydraulic pumps on the rotor. The rings are pure copper with a hard silver wear surface. Each ring is contacted by two composition brushes for each circuit. "GlidCop" material provides a low resistance path for current through the cantilever brush springs. Copper shunt cables are used in parallel with the brush springs. The brush block terminal bars are made of pure copper. A combination of G-10 and phenolic barriers are sandwiched between all brush and spring assemblies and terminal blocks. This combination maintains dielectric integrity between circuits.

25 A Power Circuits

The sliprings and brushes for these circuits are rated 25A, and 600V. Each ring is contacted by two composition brushes for each circuit. The materials and configurations for these rings and brushes are identical to those used in the 80A power circuits.

Command and Control Circuits

The sliprings and brushes for these circuits are rated at 5A, and 600V. Each ring is contacted by two composition brushes for each circuit. The materials and configurations of these rings and brushes are identical to those used in the 80A circuits, except that shunt cables are not necessary on the brush springs.

Signal Circuits

Sliprings and brushes for signal circuits are rated at 1A, and 125V. Each ring is contacted by two composition brushes per circuit. The materials and configurations of these rings and brushes are identical to those used in the command and control circuits.

ELECTRICAL CONNECTIONS

Rotor Connections

All power circuits terminate in a completely enclosed terminal area, which is easily accessible through gasketed covers. Each circuit terminates in feed-through screw clamp terminal blocks, of the size required to meet the current capacity and wire size of the respective circuits.

The signal circuits terminate in the same area as the power circuits, but they are isolated from each other. Each circuit terminates in feed-through screw clamp terminal blocks, of the size required to meet the current capacity and wire size of the circuits.

Stator Connections

All power circuits terminate in brush blocks by means of screw terminals. This design avoids crimping or soldering, which might cause problems with the large conductors.

All signal circuits terminate in brush blocks by means of a crimp-type terminal lug and attaching hardware.

Shielding

Metallic brushes are used to provide a continuous metallic shield across the rotating interface of the slipring housing. The brushes and metallic gaskets on terminal covers of the slipring assembly provide protection against damage caused by lightning induced surges, for equipment connected to cables routed to the blades through the rotor sliprings.

Position Sensor

The position sensor is installed and wired by the slipring manufacturer. The sensor is mounted inside the brush block area with servo cleats. The sensor can be adjusted and replaced in the field by removing the gasketed brush block cover.

8.6 CABLING

The insulation on all conductors for 480 Vac service is rated at 600 V. The insulation on conductors for 4160 V service is rated at 5,000 V. All insulation is oil resistant, flame retardant and self-extinguishing. Additional insulation for high voltage, power and instrumentation circuits is provided by routing each group in separate conduits or wireways.

All conductors are stranded copper. NEMA class E or C stranding is used for fixed wiring and class G or H stranding is used for movable wiring and loops across flexible joints. The conductor size for power wiring was chosen so that the line losses at the rated load are less than 2%. Where loads are not significant, the minimum wire size for all conductors between boxes, panels, cabinets and devices is No. 14 AWG for control wiring and No. 16 AWG for instrumentation wiring. The minimum wire size for internal wiring, where both conductors terminate inside a single device, cabinet, box or panel enclosure is No. 16 AWG for control wiring and No. 22 AWG for instrumentation wiring.

To minimize noise, all analog instrumentation conductors are twisted and shielded. The shields are grounded at the signal processing end.

Power cable terminals use compression screws bearing on a captive wire inserted in the hole of a terminal block or lug. Crimp connections are used only where space prohibits the use of lugs or where the crimp is part of an approved termination device.

A ground conductor provides a positive connection from the generator lightning arrestors, surge capacitors and grounding transformer. The path to ground goes to the tower foundation rebar structure and ground grid. Bonding straps cross all major structural joints, including the joint between the tower base and the tower foundation rebar structure and ground grid. Flexible bonding strap loops connect moving structural elements with a limited range, such as the ailerons. Vertical runs of conduit or wireway for conductor size 0 AWG or smaller, other than cable-bus, is supported at a minimum of every 20 ft, starting at the top of the tower.

All cabling is protected by conduits or wireways. In the vicinity of hydraulic or lubrication components wireways are sealed against oil. Flexible metal conduit is sealed against liquid in areas where flexibility or installation required it. Cable-bus for the generator output cable is used for the vertical run down the tower and in the trench to the electrical equipment building, because of its support system and free air current rating. Cable supports are provided every 1.5 ft.

All conduit and wireway joints assure electrical continuity around the conduit or wireway, and electrical continuity across the joint.

All cabling has been chosen to withstand ambient temperatures of -40° to +50°C, without any deterioration in the insulation over the 30-year design life.

8.7 SWITCHGEAR

The indoor switchgear assembly is housed in the electrical equipment building. The assembly provides generator rotor circuit short or tie to the utility, cycloconverter tie to the utility, load break for the service transformer feed and metering and protective relay functions. These functions are shown in Figure 8-14, a one-line diagram, as stator short, stator tie, cycloconverter tie, metering, relays, and the fused disconnect shown on the 4160V side of the 300 kVA service transformer.

The switchgear assembly, shown in outline form in Figure 8-15, conforms to the requirements listed in Table 8-9 and contains the elements listed in Tables 8-10 through 8-14.

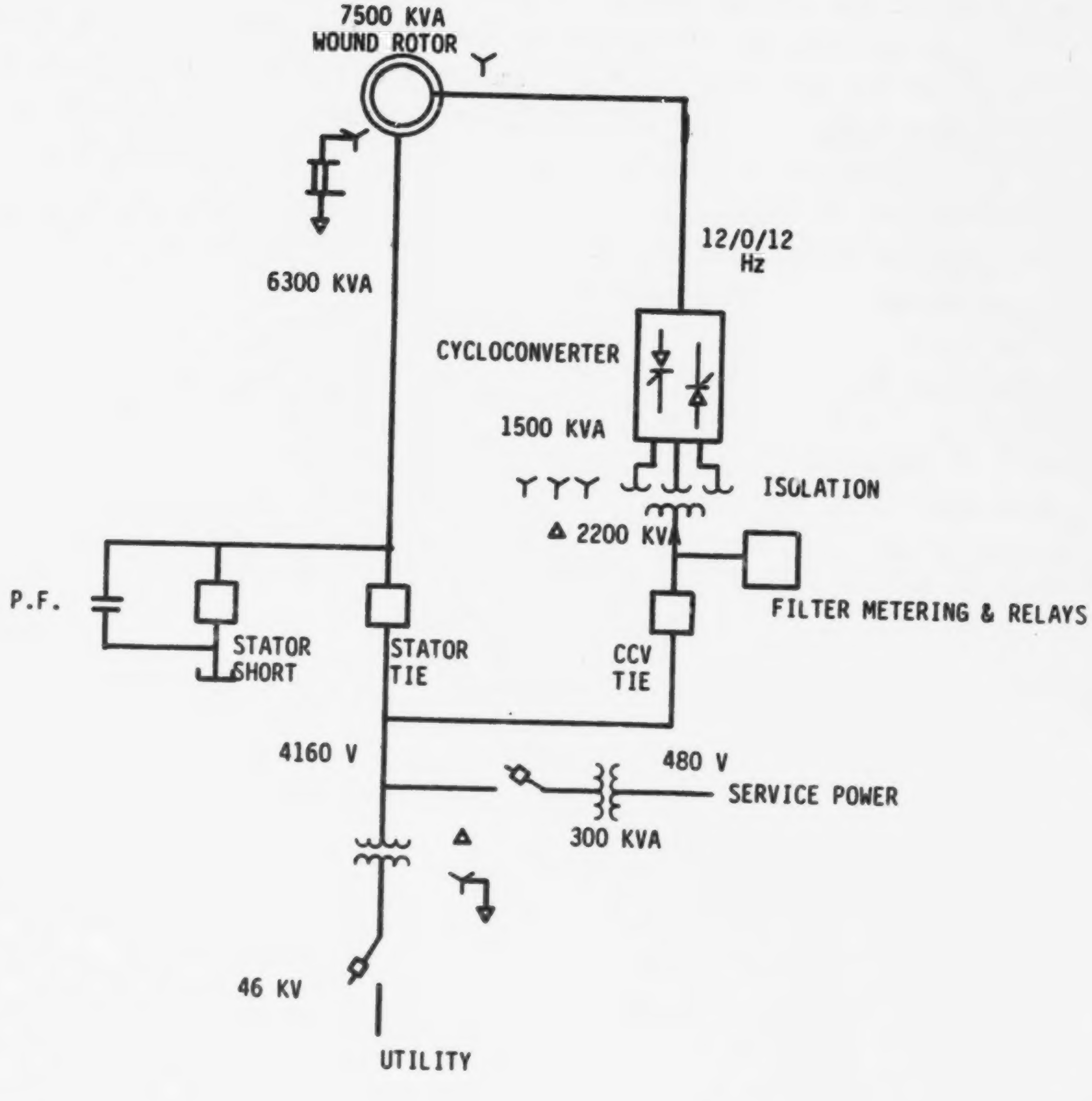
7500 KVA
WOUND ROTOR
6300 KVA
12/0/12
Hz
CYCLOCONVERTER
1500 KVA
ISOLATION
2200 KVA
FILTER METERING & RELAYS
P.F.
STATOR
SHORT
STATOR
TIE
CCV
TIE
4160 V
480 V
SERVICE POWER
300 KVA
46 KV
UTILITY

Figure 8-14 WTG Simplified One-Line Diagram

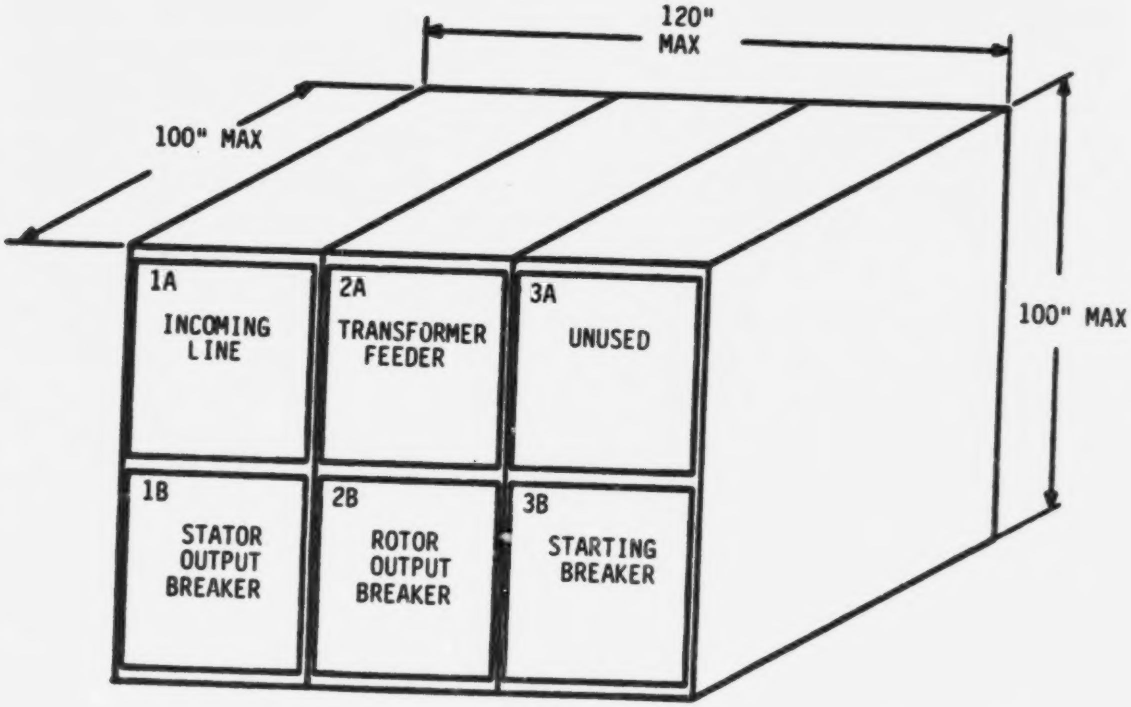
120" MAX
100" MAX
100" MAX
1A
INCOMING LINE
2A
TRANSFORMER FEEDER
3A
UNUSED
1B
STATOR OUTPUT BREAKER
2B
ROTOR OUTPUT BREAKER
3B
STARTING BREAKER

Figure 8-15 MOD-5A Switchgear Assembly

Table 8-9 Requirements

Environment	Ambient temperature: -30°C to + 40°C Altitude: 0 to 3300 ft. (Derated above 3300 ft.)
Structure	Rigid, self-supporting, completely metal-enclosed structure
Circuit Breaker Compartments	To house 4160 V circuit breakers with removable elements and including grounded metal safety shutters
Ground Bus	.25 in. by 2 in. ground bus throughout the lineup
Bus Compartment	Main bus rated at 2000 A continuous service and braced to withstand forces equal to power circuit breaker close, carry and interrupt ratings
Materials	Protected from corrosion due to exposure to airborne moisture and 0.005 ppm of salt
Heaters	300 W per section to minimize moisture condensation
Size	100 in. high, 100 in. deep, 120 in. long, maximum
Weight	15,000 lbs. maximum
Circuit Breakers	4160 V, 60 Hz with continuous rating as listed in Tables 8.7-3, 5, 6 and an interrupt rating of 250 MVA. Operated by an electrically trip-free stored-energy mechanism.
Wiring	Secondary wiring is 600 V switchboard wire

Table 8-10 Switchgear Location 1A Elements
Function - Incoming Line

DEVICE	DEVICE NO.	QUANTITY
Phase Overcurrent Relay With Voltage Restraint	50/51 V	3
Frequency Relay	81	1
Phase-Sequence Relay	47	1
Potential Transformer 4800/120	PT3	3
Current Transformer 1500/5	CT5	3
Lightning Arrestors 5.1 kV	--	3
Voltage Transducer 4-20 mA Output	VT-2	3
Current Transducer 4-20 mA Output	AT-2	3
Kilowatt Transducer 4-20 mA Output	WT-2	1
VAR Transducer 4-20 mA Output	VART-2	1
Watthour Meters, (1) detented to read power output, and (1) detented to read power input, 3 element, 3 phase indicating, with pulse generators for remote accumulating.	KWH	2
Voltmeter (4.5 in. square) Label = Volts, Scale = 0-6000	VM	3
Ammeter (4.5 in. square) Label = Amperes, Scale = 0-1500	AM	3
Kilowatt Meter (4.5 in. square) Label = Power, Scale = -1000/0/12000	WM	1
Kilovar Meter Label = Reactive Power Scale = -1000/0/4000	VARM	1

Table 8-11 Switchgear Location 1B Elements
Function - Stator Output

DEVICE	DEVICE NO	QUANTITY
Phase Overcurrent Relay With Voltage Restraint	50/51 V	3
4160 V Vacuum Power Circuit Breaker, 2000 A Continuous, 3 Pole, With Electrically Operated, Stored Energy Mechanism	52-2	1
Current Balance Relay	61	1
Lockout Relay	86	1
Tripping Relay	94-2	1
Synchronize Check Relay	25	1
Overvoltage Relay	59	
Differential Protective Relay	87	1
Synchroscope Switch	SS	1
Synchroscope	SYN	1
Potential Transformer 4800/120	PT-2	3
Current Transformer 1500/5	CT3 & CT4 CT3A & CT4A	12
Frequency Transducer 4-20 mA Output	FT	1
Voltage Transducer 4-20 mA Output	VT-1	3
Current Transducer 4-20 mA Output	AT-1	3
Kilowatt Transducer 4-20 mA Output	WT-1	1
VAR Transducer 4-20 mA Output	VART-1	1
Voltmeter (4.5 in. square) Label=Volts, Scale=0-6000	VM	3

Table 8-11 Switchgear Location 1B Elements
Function - Stator Output (Cont'd)

DEVICE	DEVICE NO	QUANTITY
Ammeter (4.5 in. square) Label=Amperes, Scale=0-1000	AM	3
Kilowatt Meter (4.5 in. square) Label=Power, Scale=-1000/0/12000	WM	1
Var Meter (4.5 in. square) Label=Reactive Power Scale=-1000/0/4000	VARM	1
Frequency Meter Label=Frequency, Scale=55-65	FM	1
Indicating Lamps, Breaker Open-Close, Red & Green	--	2

Table 8-12 Switchgear Location 2A Elements
Function - Transformer Feeder

DEVICE	DEVICE NO	QUANTITY
3 Phase, Fused Load Break Disconnect Switch For 300 kVA Transformer	--	1
Indicator Lamps, Disconnect - Switch Open-Close, Red & Green	--	2

Table 8-13 Switchgear Location 2B Elements
Function - Rotor Output

DEVICE	DEVICE NO	QUANTITY
4160 V Vacuum Power Circuit Breaker, 2000 A Continuous, 3 Pole, with Electrically Operated Stored-Energy Mechanism	52-1	1
Tripping Relay	94-1	1
AC Time Overcurrent Relay	51	3
Current Transformer 600/5	CT8	3
Indicating Lamps, Breaker Open-Close, Red & Green	--	2
Current Transducer 4-20 mA Output	AT-3	3
Ammeter (4.5 in. square) Label = Amperes, Scale = 0-600	AM	3

Table 8-14 Switchgear Location 3B Elements
Function - Starting

DEVICE	DEVICE NO	QUANTITY
4160 V Vacuum Power Circuit Breaker, 2000 Amperes Continuous, 3 Pole, with Electrically Operated Stored-Energy Mechanism	52-3	1
Tripping Relay	94-3	1
Current Transformer 1500/5	CT7	3
Indicating Lamps, Breaker Open-Close, Red & Green	--	2

8.8 STEP-UP TRANSFORMER

The step-up transformer matches the 4160 V output of the generator to the local utility line voltage, and provides an impedance between the generator and the utility line.

The most cost effective transformer is self-cooled up to 5,840 kVA. Oil cools the transformer using convection in heat exchangers. A set of thermostatically controlled fans provide additional cooling between 5840 kVA and 7300 kVA, or when the ambient temperature is high.

Primary protection for the transformer is provided by lightning arrestors and a manually-operated fused switch.

The outdoor, pad-mounted, oil-filled, step-up transformer is 119 in. high, 84 in. wide and 81 in. deep. It weighs 40,000 lbs. The transformer conforms to the requirements of Table 8-15. To allow for different utility line voltages, Table 8-16 shows requirements for 69 kV and 46 kV primary voltages.

The accessories for the unit are listed in Table 8-17.

Table 8-15 Transformer Requirements

Capacity	5840/7300 kVA OA/FA 65°C
Type and Frequency	60 Hz, 3 Phase
Impedance	5.5% at 5840 kVA
Primary 4 Wire	WYE connected Solidly Grounded Neutral Voltage and BIL per Table 8.8-2
Secondary 3 Wire	4.16 kV DELTA connected, 110 kV BIL
Primary and Secondary Components	Air filled, porcelain bushings with accessories
Taps (With No Load Tap Changer)	4 - 2.5% TAPS on Primary 2 UP, 2 DOWN from Rating
Expected Life	30 years
Maintenance Interval	12 Months

Table 8-16 Rating Table

PRIMARY VOLTAGE	PRIMARY BASIC INSULATION LEVEL	CURRENT-TRANSFORMER RATIO NEUTRAL	PRIMARY (WHEN REQ'D)
69 kV	250	300/5	100/5
46 kV	200	400/5	200/5

Table 8-17 Accessories

Mechanical, resealing, pressure relief device
Lifting eyes to permit pulling or hoisting transformer
Provision for rolling or skidding in any direction
Ground pads
Hand hole
Drain valve
Oil sampling device
Provision for jacking to level unit
Diagrammatic nameplate
Liquid-level gage with alarm contacts (Device 71)
Thermometer relay for fan control
Pressure-vacuum gage
Fans for operation between 5840 kVA and 7300 kVA
Winding temperature gage with alarm contacts. (Device 49)
Key interlock system to prevent compartment access unless de-energized
Anti-condensation heaters in connection compartments, for continuous operation
Base anchor bolt holes or hold down clamps

8.9 FILTER

The variable speed generator subsystem uses a cycloconverter to match the 60 Hz line frequency to the generator rotor slip frequency. A six-pulse cycloconverter minimizes the number of bridges, using a moderate harmonic level. The converter is rated at 1500 kW and provides about 15% of the system power at rated conditions. The rotor speed is 16.8 rpm, 14.3% above synchronous speed. Harmonic filters and power factor correction capacitors provide power of acceptable quality to the utility. The harmonic voltage waveform distortion will be controlled to meet the guidelines of IEEE 519, Guide for Harmonic Control and Reactive Compensation of Static Power Converters. The reactive power will be controlled to near zero in the baseline operating mode. Voltage may be controlled instead of reactive power.

When the MOD-5A program was stopped, the detailed design of the filters and capacitor installation was not done. The following paragraphs discuss the design considerations involved in the filter analysis and specification.

The cycloconverter controller, described in section 9.1.5, maintains a power factor of 1.0 at the utility grid. Control difficulty is minimized if a fixed capacitance partially compensates for the inductance of the generator stator. Tuned shunt filters provide a path with low impedance for current harmonics produced by the converter. The filter capacitors provide some of the power factor capacitance. As shown in Figure 8-11, the filters are electrically located on the 4.16 kV bus, between the converter and its primary circuit breaker. This location allows the circuit breaker to protect the filters and switch them out of the system when the wind turbine generator is not operating. In a cluster installation, a centralized filter installation is an alternative.

Harmonics at 6n ±(n=1,3,5,etc.) multiplied by 60 Hz, and similar multiples of slip frequency must be filtered. Shunt filters were to be tuned to the 5th, 7th, and 11th harmonics. The filters also provide a roll-off, to suppress higher harmonics. The filter design would include suppression of slip frequency harmonics. The typical harmonic content in the converter's output current is shown in Figure 8-16. The isolation transformer helps to reduce higher harmonics. As the converter output is only 15% of the system output.

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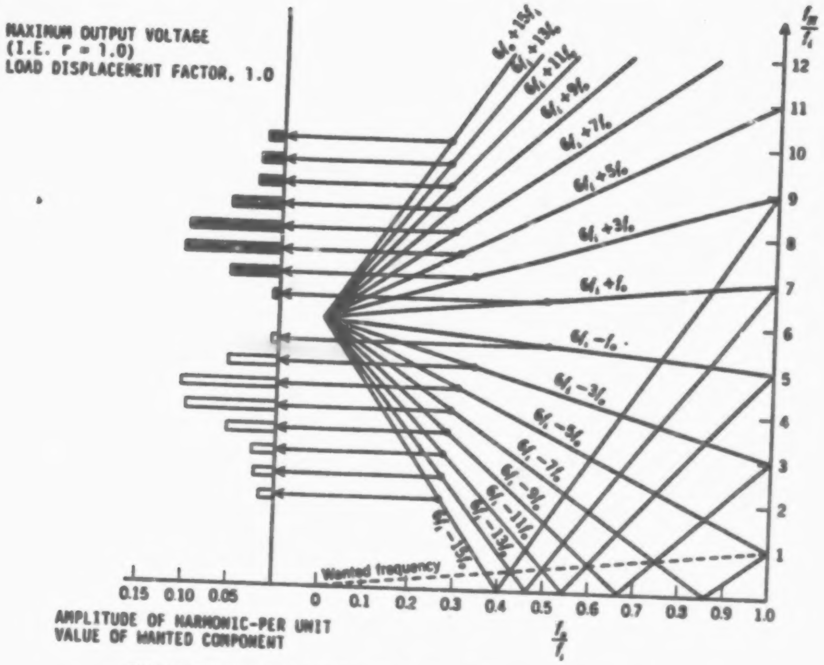

CHARTS SHOWING THE AMPLITUDES OF THE PREDOMINANT HARMONIC COMPONENTS IN THE OUTPUT VOLTAGE OF THE 6-PULSE CYCLOCONVERTER, WITH MAXIMUM OUTPUT VOLTAGE AND UNITY LOAD DISPLACEMENT FACTOR, AND THE RELATIONSHIPS BETWEEN THE HARMONIC FREQUENCIES AND THE OUTPUT TO INPUT FREQUENCY RATIO.

PELLY, B.R., THYRISTOR PHASE-CONTROLLED CONVERTERS AND CYCLOCONVERTERS. WILEY-INTERSCIENCE, 1971.

Figure 8-16 Harmonic Current Levels

it is possible that less filtering would be necessary. For example, a voltage distortion of 5% is permitted by IEEE 519 for utility connections below 69 kV. The 60 Hz harmonic amplitudes vary with the inverse of the harmonic number, so the largest 5th harmonic would have an amplitude of 20% x 15% = 3%. Combining the other harmonics in a root-sum-squared yields a sum of 5%. GE-HECO and IEEE 519 power quality values are shown in Table 8-18.

A simplified harmonic waveform is shown in Figure 8-17. The stator's 60 Hz waveform, the rotor's unfiltered waveform and the sum are shown. Note that the apparent distortion is not severe.

The harmonic analysis of the system consists of several sections. The first is the development of a one-line diagram of the system, including portions of the utility company system. These lines, transformers and distributed capacitance must be identified so that the system impedance, as seen by the wind turbine generator, is accurately represented. Potential changes in the system's impedance, as a result of switching operations, will be identified.

After a satisfactory model of the system is developed, calculations will be made to determine possible resonant frequencies for the various impedances on the utility tie lines caused by switching.

The system will be modeled on a digital, harmonic level flow program to calculate the magnitude of harmonic currents over a range of frequencies. These calculations will be repeated many times over the generator's operational speed range of 80% to 120% of synchronous speed. The cycloconverter develops different harmonic frequencies at different generator speeds. Some of the operating speeds may develop resonances that could require a filter reactor.

Finally, various filter designs will be checked for operation over the total speed range. This data would be analyzed and reduced to a set of filter design constants.

Table 8-18 Power Quality

HECO/GE

(Under measurement conditions mutually agreed to by GE and HECO)

Voltage	- 46KV ± 5% 3Ø, 60 Hz
Superimposed Voltage	- Not to exceed 2V on 115V system
Frequency	- ± 0.1 Hz Normal ± 0.4 Hz Abnormal 3 Per Day

IEEE 519

(Guidelines)

Line Notching	- 175000 VμS 5% D.F.
Harmonics	- Filter to < 5% (46KV)
Telephone (TIF)	- I*T coordination with telephone company
Flicker	- Fix if occurs
PF Correction	- Near 1.0 PF, VAR regulate with filter, PF caps

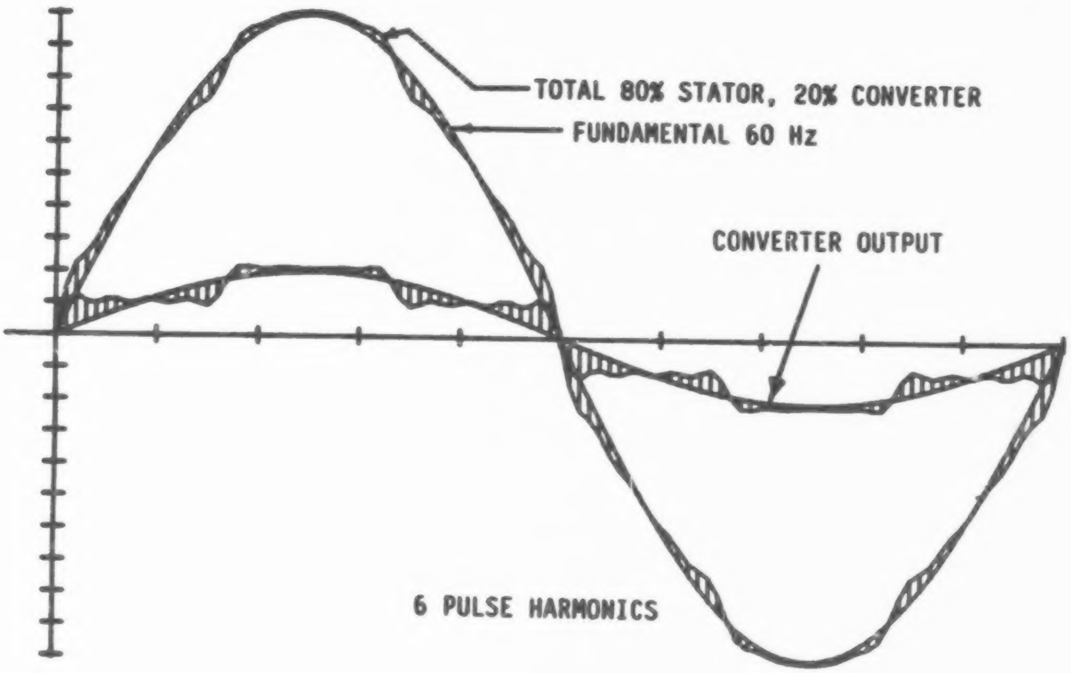
TOTAL 80% STATOR, 20% CONVERTER
FUNDAMENTAL 60 Hz
CONVERTER OUTPUT
6 PULSE HARMONICS

Figure 8-17 Simplified Harmonic Waveform

8.10 ELECTRICAL SERVICE

Power for the hydraulic pumps, cooling fans, heaters, controls, and lights is provided by the electrical service distribution subsystem. This subsystem includes, one 4160 V/480 V transformer, two 480 V/208 Y 120 V transformers, four panel boards with circuit breakers for protection and associated interconnecting cabling. The service distribution subsystem is shown in Figure 8-18. The service transformers are described in Table 8-19.

Large pump motors and other large loads, such as the rotor hydraulic power pump and the cycloconverter, are powered by 480 V, 3Ø to keep current and wire size to reasonable levels. Intermediate loads, such as the equipment building heaters and nacelle hoist, are powered by 208 V, 3Ø or 208 V, 1Ø. Lights, outlets and other more common loads are powered by 120 V, 1Ø.

The wind turbine generator cannot operate without a utility grid connection. If the utility line fails, the wind turbine generator will automatically execute an orderly shutdown. Power to operate the controller, hydraulic valves, the aircraft warning strobes, and the controls cabinet heating and cooling is provided by an uninterruptible power supply and its independent distribution system. Power to operate the high voltage switchgear is provided by the station batteries.

The expected loads for the electrical service distribution system are listed in Table 8-20. The total sum of all expected loads is about 256 kVA. Obviously, for normal operation, not all loads will be on at any one time. For example, heaters and coolers for a particular subsystem are mutually exclusive. Therefore the 300 kVA main service transformer is adequate and does allow for additional service loads.

Cables carrying the 480V, 3Ø service power to the nacelle are sized at 4/0 AWS to keep the voltage drop to 2% or less. The 120V, 1Ø power from the uninterruptible power supply to the nacelle for operating the controls is carried by two separate circuits. One circuit, which powers the controls cabinet heating and cooling, solenoid valves and the aircraft warning strobes, uses three No. 2 1WS cables. The second circuit, for controller power, uses two No. 6 AWS cables. Three spare No. 2 AWS, 600 V cables to the nacelle are available.

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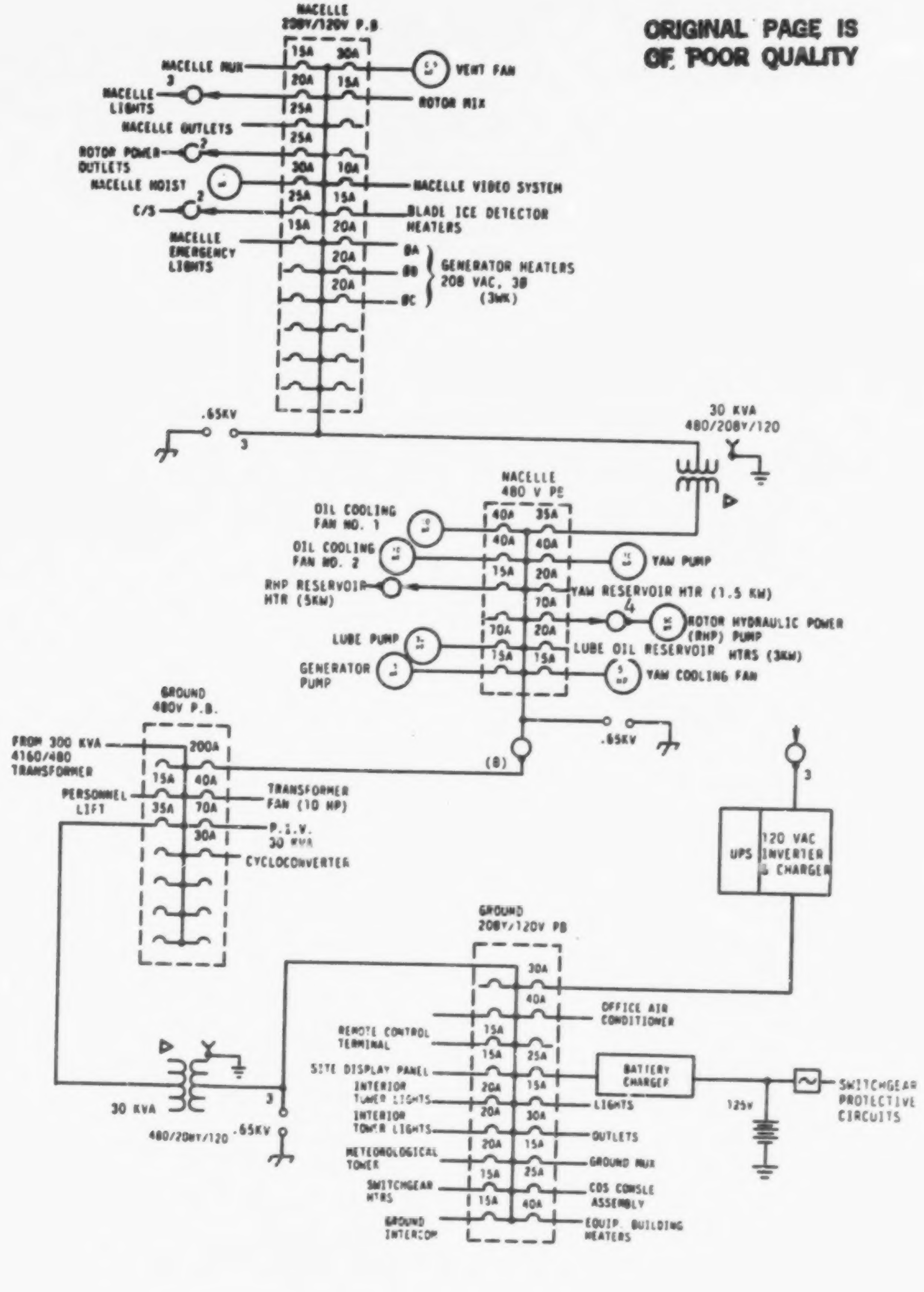
NACELLE
208Y/120V P.B
NACELLE MUX
VENT FAN
NACELLE LIGHTS
ROTOR MIX
NACELLE OUTLETS
ROTOR POWER OUTLETS
NACELLE HOIST
NACELLE VIDEO SYSTEM
C/S
BLADE ICE DETECTOR HEATERS
NACELLE EMERGENCY LIGHTS
ØA
ØB
ØC
GENERATOR HEATERS
208 VAC, 3Ø
(3WK)
15A
30A
20A
15A
25A
25A
30A
10A
25A
15A
15A
20A
20A
20A
.65KV
30 KVA
480/208Y/120
NACELLE
480 V PB
OIL COOLING FAN NO. 1
OIL COOLING FAN NO. 2
YAW PUMP
RHP RESERVOIR HTR (5KW)
YAW RESERVOIR HTR (1.5 KW)
ROTOR HYDRAULIC POWER (RHP) PUMP
LUBE PUMP
LUBE OIL RESERVOIR HTRS (3KW)
GENERATOR PUMP
YAW COOLING FAN
40A
35A
40A
40A
15A
20A
70A
70A
20A
15A
15A
(8)
.65KV
GROUND
480V P.B.
FROM 300 KVA 4160/480 TRANSFORMER
200A
15A
40A
PERSONNEL LIFT
TRANSFORMER FAN (10 HP)
35A
70A
P.I.V. 30 KVA
30A
CYCLOCONVERTER
UPS
120 VAC INVERTER & CHARGER
GROUND
208Y/120V PB
30A
40A
OFFICE AIR CONDITIONER
REMOTE CONTROL TERMINAL
15A
15A
25A
SITE DISPLAY PANEL
BATTERY CHARGER
SWITCHGEAR PROTECTIVE CIRCUITS
125V
INTERIOR TOWER LIGHTS
20A
15A
LIGHTS
INTERIOR TOWER LIGHTS
20A
30A
OUTLETS
METEOROLOGICAL TOWER
20A
15A
GROUND MUX
SWITCHGEAR HTRS
15A
25A
CDS CONSLE ASSEMBLY
GROUND INTERCOM
15A
40A
EQUIP. BUILDING HEATERS
30 KVA
480/208Y/120
.65KV

Figure 8-18 Electrical Service

Table 8-19 Service Transformers

300 KVA

- 4160/480 V
- 3 PHASE
- OIL IMMERSED
- SELF COOLED
- PAD MOUNTED
- OUTDOOR UNIT
- 71 IN. HIGH, 81 IN. WIDE, 92 IN. DEEP
- 5000 LBS
- SPECIFICATION 47A380068

30 KVA (GROUND)

- 480/208 Y 120
- 3 PHASE
- SELF COOLED
- BASE MOUNTED
- OUTDOOR UNIT
- 31 IN. x 24 IN. x 16 IN.
- 300 LBS
- GE #9T23B3872G62

30 KVA (NACELLE)

- 480/208 Y 120
- 3 PHASE
- SELF COOLED
- ELECTROSTATICALLY SHIELDED
- BASE MOUNTED
- OUTDOOR UNIT
- 31 IN x 24 IN. x 16 IN.
- 280 LBS
- GE #9T23B387263

Table 8-20 Electrical Service Summary

ITEM	FUNCTION	HP	VOLTAGE	CURRENT	PH	PF	KVA	KW	LOC
1.	Rotor Reservoir Heater	0.	480.	24.08	3	1.00	20.00	20.00	R
2.	Rotor Hydraulic Pump	10.00	480.	14.00	3	0.90	11.63	10.46	R
3.	120V Rotor Power/Outlets	0.	120.	20.00	1	1.00	2.40	2.40	R
4.	120V Rotor/Nacelle Controls	0.	120.	20.00	1	1.00	2.40	2.40	R
5.	Rotor Multiplexer	0.	120.	1.70	1	1.00	0.20	0.20	R
6.	Blade Ice Detector Heaters	0.	120.	10.00	1	1.00	1.20	1.20	R
7.	Nacelle Emergency Lights	0.	120.	4.00	1	1.00	0.48	0.48	N
8.	Nacelle Lights	0.	120.	15.00	1	1.00	1.80	1.80	N
9.	Nacelle Convenience Outlets	0.	120.	20.00	1	1.00	2.40	2.40	N
10.	Nacelle Multiplexer	0.	120.	1.70	1	1.00	.20	.20	N
11.	Nacelle Vent Fan	0.50	120.	9.80	1	0.90	1.18	1.06	N
12.	Generator Heater	0.	208.	8.30	3	1.00	3.00	3.00	N
13.	Intercom	0.	120.	10.00	1	1.00	1.20	1.20	N
14.	Nacelle Hoist	1.00	208.	3.96	3	0.90	1.42	1.28	N
15.	Oil Cooling Fan No. 1	10.00	480.	14.00	3	0.90	11.63	10.46	N
16.	Oil Cooling Fan No. 2	10.00	480.	14.00	3	0.90	11.63	10.46	N
17.	Lube Pump	30.00	480.	40.00	3	0.90	33.22	29.89	N
18.	Generator Heater	0.	208.	8.33	3	1.00	3.00	3.00	N
19.	Lube Oil Reservoir Heaters	0.	480.	10.83	3	1.00	9.00	9.00	N
20.	Yaw Reservoir Heaters	0.	208.	9.62	1	1.00	2.00	2.00	N
21.	Yaw Pump	10.00	480.	14.00	3	0.90	11.63	10.46	N
22.	Personnel Lift	3.00	480.	5.00	3	0.90	4.15	3.74	T
23.	Transformer Fans	30.00	480.	40.00	3	0.90	33.22	29.89	G
24.	Portable Instrumentation Van	0.	480.	36.00	3	1.00	29.89	29.89	G
25.	Enclosure Heaters	0.	208.	15.00	3	1.00	5.40	5.40	G

HP - Horsepower
PH - Phases
PF - Power Factor

Table 8-20 Electrical Service Summary (Continued)

ITEM	FUNCTION	HP	VOLTAGE	CURRENT	PH	PF	KVA	KW	LOC
26.	Regulator	0.	208.	10.00	3	1.00	3.60	3.60	G
27.	Battery Charger	0.	208.	20.00	3	1.00	7.20	7.20	G
28.	Interior Tower Lights	0.	120.	15.00	1	1.00	1.80	1.80	T
29.	Interior Tower Outlets	0.	120.	20.00	1	1.00	2.40	2.40	T
30.	Intercom	0.	120.	10.00	1	1.00	1.20	1.20	G
31.	Switchgear Heaters	0.	120.	20.00	1	1.00	2.40	2.40	G
32.	Ground Enclosure Lights	0.	120.	10.00	1	1.00	1.20	1.20	G
33.	Ground Enclosure Outlets	0.	120.	15.00	1	1.00	1.80	1.80	G
34.	Ground Multiplexer	0.	120.	1.70	1	1.00	0.20	0.20	G
35.	Ground Control Interface	0.	120.	10.00	1	1.00	1.20	1.20	G
36.	Uninterruptible Power Supply	0.	120.	20.00	1	0.90	2.40	2.16	G
37.	Station Battery Charger	0.	208.	14.00	1	0.90	2.91	2.62	G
38.	Site Console Assembly	0.	120.	20.00	1	1.00	2.40	2.40	G
39.	Controls Data System	0.	120.	10.00	1	1.00	1.20	1.20	G
40.	Positioner Drive	10.	480.	14.00	3	0.90	11.63	10.46	G
41.	Cycloconverter Heaters	0.	120.	16.67	1	1.00	2.00	2.00	G
42.	Cycloconverter Fans	5.	480.	7.00	3	0.90	5.82	5.23	G

HP - Horsepower
PH - Phases
PF - Power Factor

Location Code
R = Rotor
N = Nacelle
T = Tower
G = Ground

8.11 STATION BATTERY AND UPS

8.11.1 STATION BATTERY

Reliable switchgear operation is provided by a set of station batteries and a charger, regardless of the condition of the 60 Hz power line. During normal operation, the power for switchgear operation is provided by the battery charger, but if the battery charger fails, the batteries provide power. The batteries, battery charger, and associated alarm outputs are located in the vented room in the electrical equipment building. Their location is shown in Figure 8-19.

The characteristics of the station battery unit are listed in Table 8-21 and the characteristics of the accessories are listed in Table 8-22.

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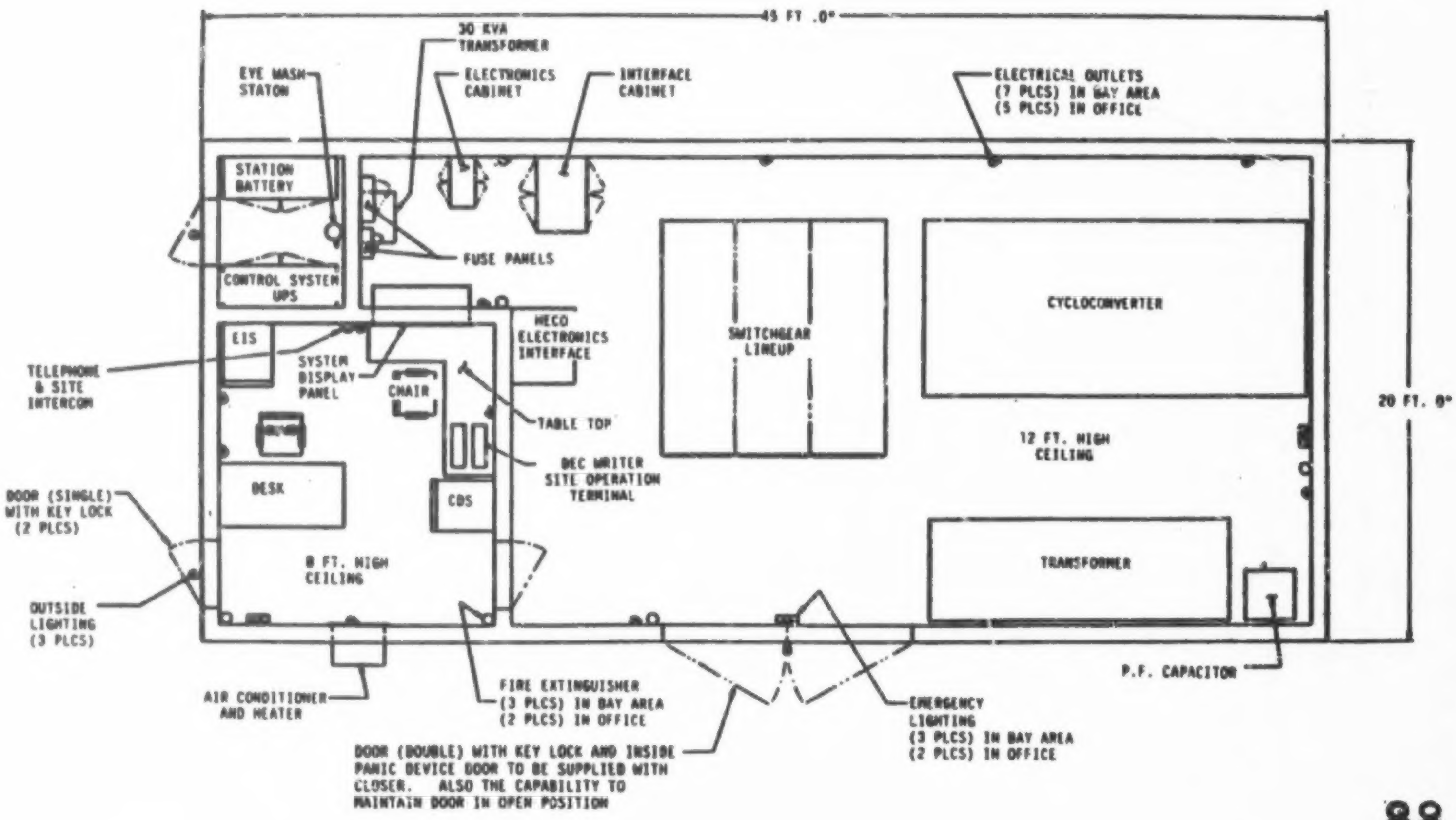
45 FT .0"
30 KVA TRANSFORMER
EYE WASH STATON
ELECTRONICS CABINET
INTERFACE CABINET
ELECTRICAL OUTLETS (7 PLCS) IN BAY AREA (5 PLCS) IN OFFICE
STATION BATTERY
FUSE PANELS
CONTROL SYSTEM UPS
EIS
SYSTEM DISPLAY PANEL
CHAIR
HECO ELECTRONICS INTERFACE
SWITCHGEAR LINEUP
CYCLOCONVERTER
TELEPHONE & SITE INTERCOM
TABLE TOP
DEC WRITER SITE OPERATION TERMINAL
12 FT. HIGH CEILING
20 FT. 0"
DESK
CDS
DOOR (SINGLE) WITH KEY LOCK (2 PLCS)
8 FT. HIGH CEILING
TRANSFORMER
OUTSIDE LIGHTING (3 PLCS)
P.F. CAPACITOR
AIR CONDITIONER AND HEATER
FIRE EXTINGUISHER (3 PLCS) IN BAY AREA (2 PLCS) IN OFFICE
EMERGENCY LIGHTING (3 PLCS) IN BAY AREA (2 PLCS) IN OFFICE
DOOR (DOUBLE) WITH KEY LOCK AND INSIDE PANIC DEVICE DOOR TO BE SUPPLIED WITH CLOSER. ALSO THE CAPABILITY TO MAINTAIN DOOR IN OPEN POSITION

Figure 8-19 Electrical Equipment Building

Table 8-21 Station Battery Characteristics

Battery Type	Lead calcium
Battery Capacity	50 A-hr (8 hr. discharge rate to 1.75V per cell)
Battery Voltage	125V
Charger Voltage	Maintains output at 132 to 135V
Charger Capacity	Supplies 10A continuously. Can restore batteries from 1.75V per cell to full charge in 12 hrs.
Charger Input Power	208V, 60Hz, 10

Table 8-22 Station Battery Accessories

Charger Alarm	Contacts open at 80% of output rated voltage
AC Power Alarm	Contacts open on loss ac power to battery charger
Meters	dc ammeter and voltmeter with ±2% accuracy
Short circuit protection	Fuse on battery output

8.11.2 UNINTERRUPTIBLE POWER SUPPLY (UPS)

The wind turbine generator cannot operate without power. Loss of the utility line tie will cause an orderly shutdown. AC power operates the control system, which includes system controller and some hydraulic valves, during normal operation. During a utility power failure, this power is provided by a battery reservoir, through the uninterruptible power supply. The uninterruptible power supply provides 3 kVA for 30 minutes. The aircraft warning strobe lights atop the nacelle are also powered by this source.

The unit is configured to provide power at all times by way of the inverter shown in Figure 8-20. Power to the inverter comes from the charger/rectifier during normal operation and from the battery reservoir during a power failure. The inverter is synchronized with the 60 Hz line. If the inverter fails, an alarm will be initiated and an automatic transfer will enable power to be drawn from the 120 Vac, 60 Hz input. Alarms are also initiated when the input ac power is lost, or when the battery voltage is low.

The uninterruptible power supply is located in a vented room of the electrical equipment building, along with the station batteries. Their location is shown in Figure 8-19.

The characteristics of the uninterruptible power supply are shown in Table 8-23 and those of the accessories are listed in Table 8-24.

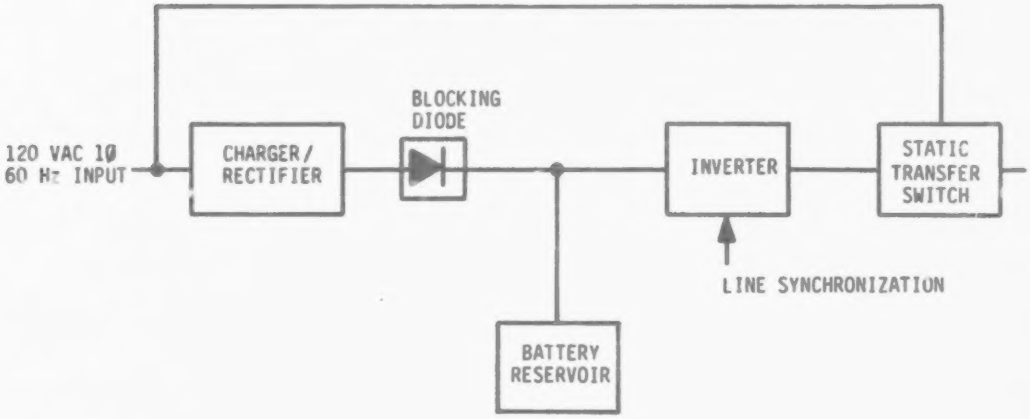
120 VAC 1Ø
60 Hz INPUT
CHARGER/
RECTIFIER
BLOCKING
DIODE
INVERTER
STATIC
TRANSFER
SWITCH
LINE SYNCHRONIZATION
BATTERY
RESERVOIR

Figure 8-20 Uninterruptible Power Supply (UPS)

Table 8-23 UPS Characteristics

Input	120Vac, 1Ø, 60Hz
Output	120Vac, 1Ø, 60Hz, 3KVA
Voltage Regulation	±3%
Wave Shape	±5% maximum harmonic distortion
Power Factor (max)	0.8 lagging or 0.8 leading
Frequency	60 ±1Hz
Overload	125% of rated load for 15 minutes while maintaining ±3% regulation
Current Limiting	Survive an output short circuit indefinitely
Battery Reservoir	Provides 30 minutes at 3kVA
Battery Life	15 years with normal operation and routine maintenance
Static Transfer	Switch to auxiliary bypass power in less than 4msec

Table 8-24 UPS Accessories

AC Power Input Alarm	Contacts open on loss of ac input power
Battery Alarm	Contacts open on low battery voltage
Transfer Alarm	Contacts open on transfer to auxiliary bypass power
Meters	Panel meters to monitor: ac output voltage ac output current output frequency battery voltage

8.12 LIGHTNING PROTECTION

Lightning Technologies Incorporated (LTI), of Pittsfield, Massachusetts evaluated and recommended the lightning protection for the MOD-5A wind turbine. The evaluation considered strike probability, conducting lightning stroke currents to ground, and circuit protection.

The requirements for protection against structural damage, power circuit protection, and instrumentation and control circuit protection are summarized in Tables 8-25, -26, -27, respectively.

The lightning protection for the instrumentation and control system includes:

- an electromagnetic interference shield across the rotor slipring assembly,
- continuous conduits for control and signal wiring between the rotor slipring and the sensors and actuators on the yoke, hub, and blade,
- separating the control and data instrumentation signal wiring, since the data instrumentation wiring can be sacrificed.

Hybrid circuit protectors limit the maximum voltage and dissipate energy. They are used to protect sensitive electronic circuits.

Table 8-25 Requirements for Protecting the Structure Against Lightning

ITEM		DESCRIPTION
Blade Tip	-	Sacrificial metal cap, minimum gap contact with outer span
Outer Span	-	Full coverage metal screen or equivalent
Aileron Bearings	-	Flexible jumpers, AWG#6 copper or equivalent, low impedance
Aileron Structure	-	Minimum gap contact with outer span protection, bonded to inner blade protection. Bolted interfaces suitable locally.
Inner Blade	-	Leading edge metal strip, AWG#4 copper or equivalent, and conduit and piping used as conductors. Strip bonded to conduit or pipe at a minimum of 4 locations on each blade, using straps around both blade surfaces. Trailing edge conductors at bonding locations.
Teeter Area	-	Bonding jumpers, #8 AWG copper or equivalent at each brake rod location for transfer from inner blade to yoke. Brushes at the interface between the brake and rod are acceptable. No special requirements for the interface between the yoke and shaft as tensioned bolted interface is suitable.
Rotor Bearing	-	4 equally spaced brushes shunting both bearings, at least 1 square in., mounted on forward end of spindle and by stopping brake.
Yaw Bearing	-	Same as rotor bearing, although damage is not likely with no protection.
Tower/Foundation	-	Anchor stud ring welded to rebar, and rebar to rebar continuity, and a visible AWG#2 bare copper cable welded between the tower base anchor ring and rebar. Foundation rebar is presumed to be adequate tc transfer current to earth, subject to geophysical evaluation of the site.

Table 8-26 Requirements Protecting the Power Circuits Against Lightning

ITEM		DESCRIPTION
Inter-Foundation Connections	-	Routed in metal conduit, electrically continuous, and a shield conductor, AWG#2 minimum, bonded to ground systems at both ends.
Utility Connection	-	Shield/Ground/Neutral conductor (4 wire wye).
Transformer	-	Station class arrestors of appropriate voltage located at interface bushings. If underground cable is used for connection, cable protecting arrestors at the pothead and cable terminations are also necessary.
Generator Voltage Bus	-	Station class arrestors at the bus side of the ground enclosure and generator ends of connection.
Generator	-	Wavefront shaping capacitors at generator connection, and arrestors.
Auxiliary Circuits	-	480, 208, 120 Vac, including separate neutral conductors require voltage limiting protection at transformers and distribution panels.

Table 8-27 Requirements for Protecting the Signal, Control and Instrumentation Circuits Against Lightning

ITEM		DESCRIPTION
Blade Permanent Wiring	-	Route in electrically continuous metal conduit with hybrid protectors on all wires where entry or exit from the conduit shield is provided. Minimum size conductors provided from sensor to minimize exploding wire damage. Shielding carried to sensor where appropriate.
Non-Permanent Wiring	-	Strain gages considered to be sacrificial. Wiring routed on exterior of blade. All wires surge protected at shield entry on yoke to protect connected electronics.
Shielding Breaks	-	Suppression of all leads at breaks in 360° shielding or assurance of shield continuity. Rotor slipring housing requires equivalent of full brush contact around bearing and conduit exit bonding to avoid circuit suppression.
Equipment Enclosures	-	Continuous shielding and suppression at terminations. Separation of incoming and suppressed wiring as practical is preferred.

8.13 UTILITY INTERFACE CHARACTERISTICS

The baseline utility power connection interface is the fused switch on the utility's side of the site's step-up transformer. The interface can be an oil circuit breaker if the utility considers it necessary. Voltage from the utility must be available for operation. A voltage block relay, to prevent the utility from reclosing onto a live wind turbine line, was recommended to Hawaiian Electric Company (HECO) for the first unit. The utility's impedance may be from 0.05 to 0.45 per unit on the MOD-5A base of 7500 kVA and 4160 V.

A standard phone line provides a communication link between the wind turbine controller and a printing terminal located at the utility's dispatcher site. The link is used for the remote control of the wind turbine. An optional arrangement was designed for the first unit in order to use HECO's dispatch computer. HECO provides a remote multiplexing unit to send and receive control and status information. The wind turbine signals are connected as parallel digital and analog circuits at the multiplexer. The standard serial remote control is described in section 9.2.4 and the HECO interface is described in Table 8-28.

Table 8-28 Remote Utility Interface Signal List

REFERENCE NO.	SIGNAL DESCRIPTION
1	Breaker Trip - For transfer trip arrangement to assure that MOD-5A is off line immediately. Operation trips stator breaker.
2	Breaker Position - Stator breaker "A" contact indicating closed or open position.
3	Disable - Discrete signal to MOD-5A controller that initiates automatic shutdown sequence to the standby-inhibit state, disabling automatic operation.
4	Enable - Discrete signal to MOD-5A controller that initiates automatic start-up sequence from the standby state and enables automatic operation.
5	Power Set - Analog signal to MOD-5A controller to set maximum output reference to less than rating.
6	VAR Set - Analog signal to MOD-5A controller to set reactive power (or voltage) reference within permitted range.
7	Major Alarm - Discrete signal from MOD-5A controller indicating major alarm status. This is a combination of existing controller inputs.
8	Minor Alarm - Discrete signal from MOD-5A controller indicating an alarm combination that requires some maintenance action, such as filter change.
9	Intrusion Alarm - Discrete signal to remote terminal unit (RTU) indicating that site security sensors are in alarm state.
10	Warning Light Alarm - Discrete signal to RTU indicating that aircraft warning lighting needs maintenance.
11	KW - Analog signal to RTU indicating instantaneous real power flow at the MOD-5A.
12	KVAR - Analog signal to RTU indicating instantaneous reactive power flow at the MOD-5A.
13	Voltage - Analog signal to RTU indicating instantaneous 4160 V bus voltage at the MOD-5A.
14	KWH-IN - Discrete signal pulse generator to RTU for accumulating energy from detented incoming kWH meter.

Table 8-28

Remote Utility Interface Signal List (Cont'd)

REFERENCE NO.	SIGNAL DESCRIPTION
15	KWH-OUT - Discrete pulse generator signal to RTU for accumulating energy from detented outgoing kWH meter.
16	RPM - Analog signal to RTU showing instantaneous rotor speed.
17	Wind Speed - Analog signal to RTU showing instantaneous wind speed at hub height.
18	Aileron Angle - Analog signal to RTU showing instantaneous deflection angle of ailerons, δ_{ai}.
19	Wind Error - Analog signal to RTU showing wind direction at hub height relative to nacelle.
20	Yaw Heading - Analog signal to RTU showing present absolute yaw orientation.
21	Lockout - Discrete signal to RTU indicating lockout status or site controlled manual operation status.
22	Standby-Inhibit - Discrete signal to RTU indicating status.
23	Standby-Enabled - Discrete signal to RTU indicating status as enabled or in start-up or operation.
24	Start-up/Shutdown - Discrete signal to RTU indicating status in transition between standby and generate. (NOTE: Stator breaker position indicates generate state)

8.14 REFERENCES

1. Bose, B.K., A Review of AC Drives Technology, TIS 81CRD127, GE, Schenectady, N.Y., June 1981.

2. Lipo, T.A., Investigation of Variable Speed for Wind Turbine Power Generation, ECE-81-9, Department of Electrical and Computer Engineering, University of Wisconsin in Madison, August 1981.

3. Anderson, T.S., Hughes, P.S., Kirschbaum, H.S., Mutone, G.A., "Multiple and Variable Speed Electrical Generator Systems for Large Wind Turbines", Proceedings of Workshop held in Cleveland, Ohio, July 28-30, 1981, NASA Conference Publication 2230, DOE CONF-810752, SERI/CP-635-1273, pp. 125-138.

4. Douglas, R.R., "Conceptual Design of the 7 MW MOD-5B Wind Turbine Generator", Proceedings of the Fifth Biennial Wind Energy Conference and Workshop, SERI/CP-635-1340, Vol 1, pp. 169-182, October 1981.

5. Schwerchardt, H., Suchanek, V. "Converter-Fed Synchronous Generator Systems for Wind Power Plants", Brown-Boveri Review, Volume 69, pp. 57-64, Baden, Switzerland, March 1982.

6. Appiarius, J.C., Urano, A.S., System Benefits and Considerations when Using AC Adjustable Frequency Drives in Generating Stations, Presented at American Power Conference, Chicago, Illinois, April 27-29, 1981.

7. Mayer, C.B., "High Response Control of Stator Watts and Vars for Large Wound Rotor Induction Motor Adjustable Speed Drives", IEEE Transactions IAS79:27F, pp. 817-823.

8. Allen, J.A., Wyeth, W.A., Herzog, G.W., Young, J.A.I., "Electrical Aspects of the 8750 hp Gearless Ball-Mill Drive at St. Lawrence Cement Company", IEEE Transactions on Industry Applications VOL IA-11 No. 6, pp. 681-687, Nov/Dec 1975.

9. Guide for Harmonic Control and Reactive Compensation of Static Power Converters, IEEE 519, July 1979.

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9.0 CONTROL AND INSTRUMENTATION SUBSYSTEM

9.0 CONTROL AND INSTRUMENTATION SUBSYSTEMS

The major subassemblies of the control and instrumentation subsystem, shown in Figure 9-1 are:

- controller
- signal conditioning
- sensors
- emergency shutdown (ESD)
- system display panel
- operator's terminals - local and remote
- engineering instrumentation subsystem
  - controls data subsystem
  - multiplexers

9.1 CONTROL HARDWARE AND FUNCTIONS

A block diagram of the control subsystem is shown in Figure 9-2. The controller, signal conditioning, and the emergency shutdown panel are located in the nacelle in the controls equipment cabinet. Figure 9-3 shows the layout of the front panel of the controls equipment cabinet. The system display panel, operator's terminal, and the controls data subsystem are located in the office of the electrical equipment building at the base of the tower. Figure 9-4 contains a floor plan of the electrical equipment building. There are three multiplexers; one located on the yoke, one in the nacelle, and one in the electrical equipment building.

The controller is a microprocessor-based, programmable controller: the EPTAK 700, made by Eagle Signal. The basic functions of the controller are mode determination, automatic sequence operation, torque and speed control, and command and data interface.

The remote and site operator's terminals are "dumb" keyboard printers that print a summary of the operating data and transmit the operator's commands.

The control data subsystem is an engineering instrumentation subsystem that supports tests and initial operation. It receives operating data from the controller, and records and processes the data for a detailed report. The control data subsystem transmits the operator's commands to interrogate controller RAM locations and to alter operating parameters.

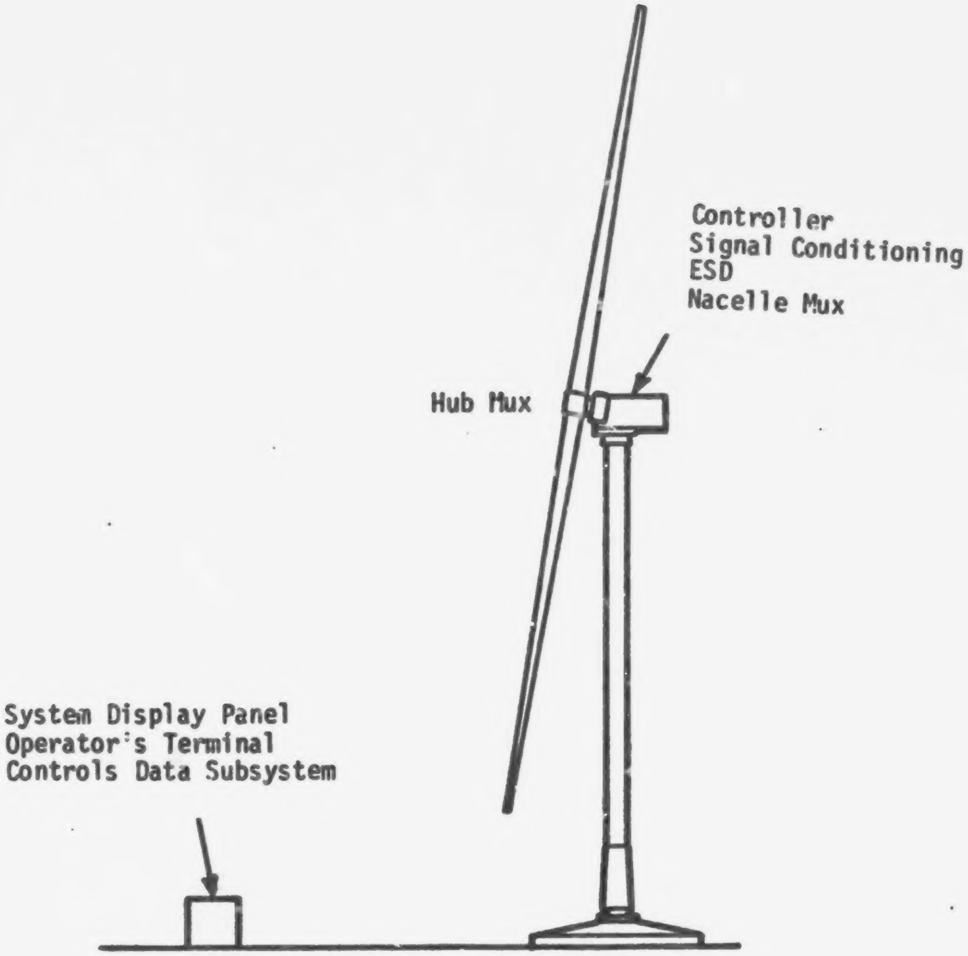
Controller
Signal Conditioning
ESD
Nacelle Mux
Hub Mux
System Display Panel
Operator's Terminal
Controls Data Subsystem

Figure 9-1 Instrumentation and Control Subassemblies

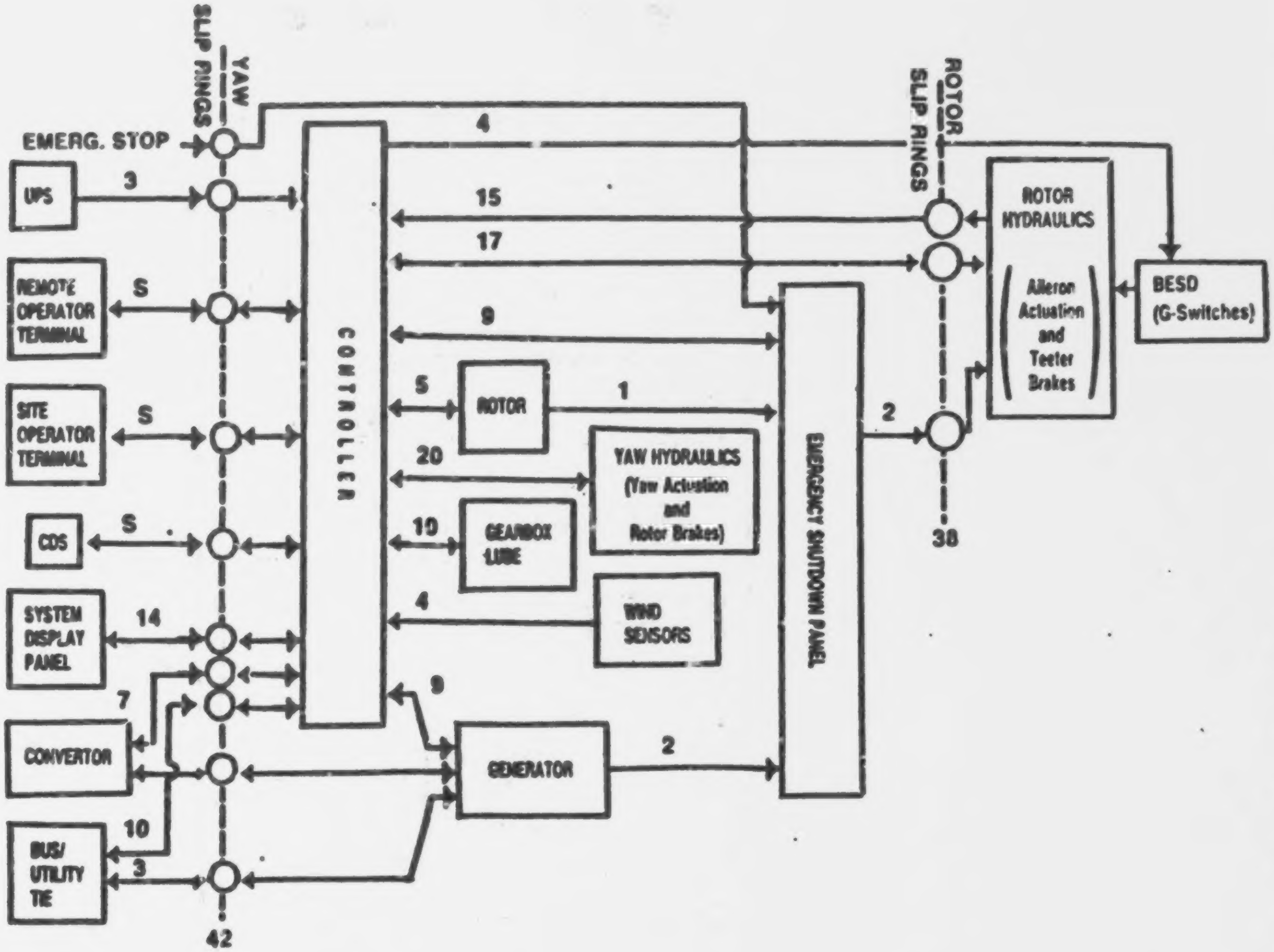
YAW
SLIP RINGS
ROTOR
SLIP RINGS
EMERG. STOP
UPS
3
REMOTE OPERATOR TERMINAL
S
SITE OPERATOR TERMINAL
S
CDS
S
SYSTEM DISPLAY PANEL
14
7
CONVERTOR
10
BUS/ UTILITY TIE
3
42
CONTROLLER
4
15
17
9
5
ROTOR
1
20
YAW HYDRAULICS (Yaw Actuation and Rotor Brakes)
10
GEARBOX LUBE
4
WIND SENSORS
9
GENERATOR
2
EMERGENCY SHUTDOWN PANEL
2
38
ROTOR HYDRAULICS
Aileron Actuation and Teeter Brakes
BESD (G-Switches)

Figure 9-2 MOD-5A Control Subsystem Block Diagram

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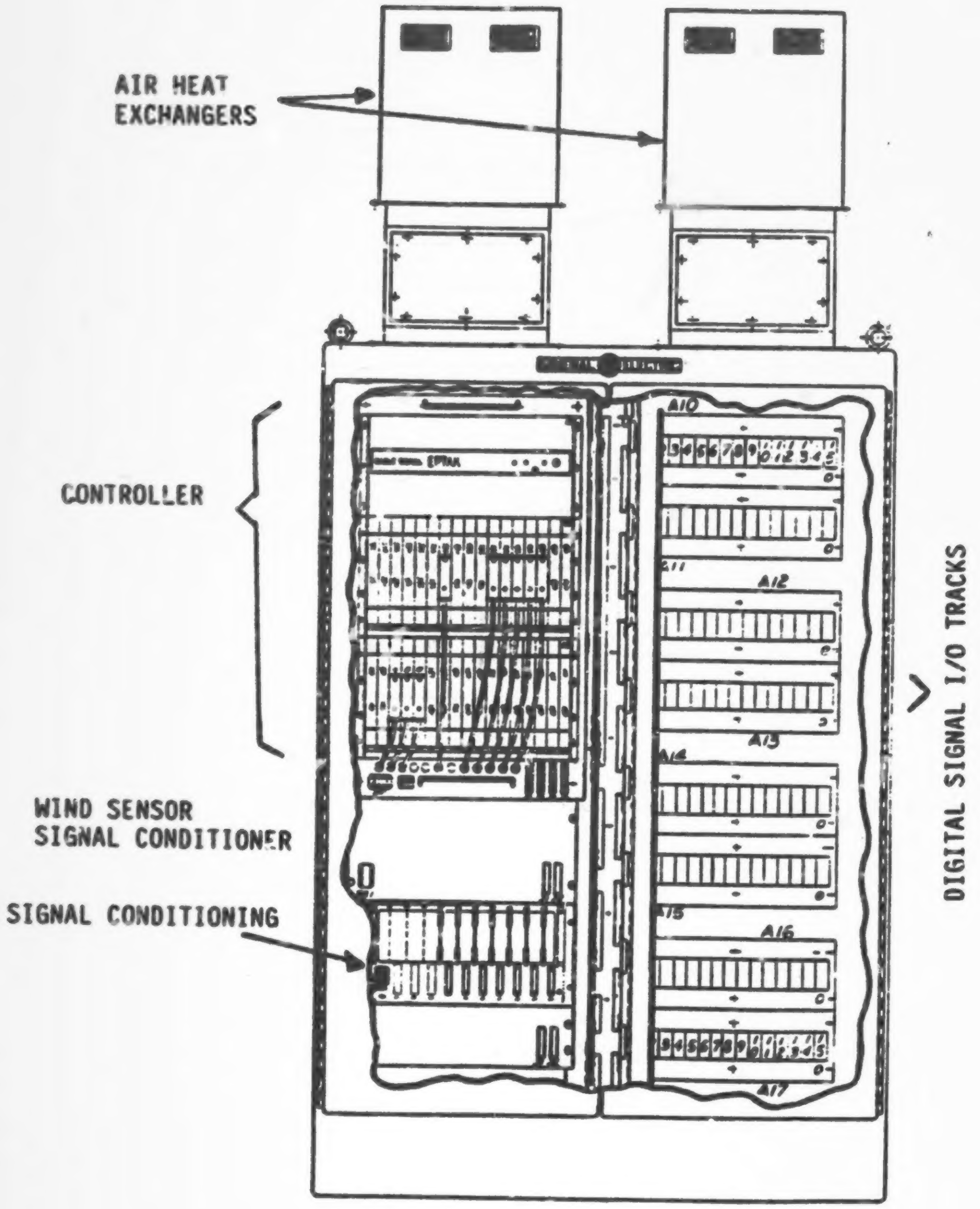
AIR HEAT
EXCHANGERS
CONTROLLER
WIND SENSOR
SIGNAL CONDITIONER
SIGNAL CONDITIONING
DIGITAL SIGNAL I/O TRACKS
A10
A11
A12
A13
A14
A15
A16
A17

Figure 9-3 Front View of the Controls Equipment Cabinet

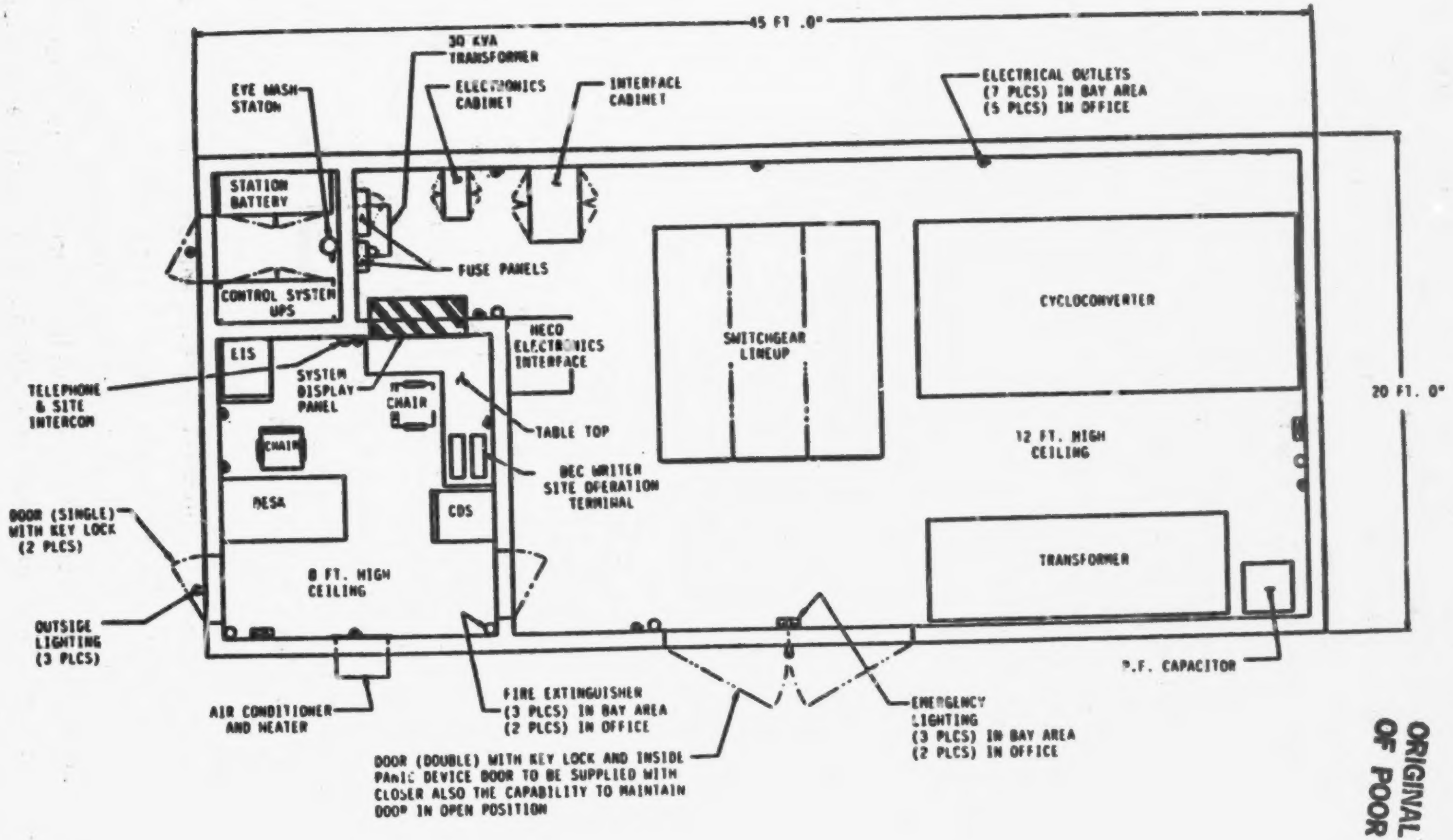
45 FT .0"
20 FT. 0"
30 KVA TRANSFORMER
EYE WASH STATON
ELECTRONICS CABINET
INTERFACE CABINET
ELECTRICAL OUTLETS (7 PLCS) IN BAY AREA (5 PLCS) IN OFFICE
STATION BATTERY
CONTROL SYSTEM UPS
FUSE PANELS
SWITCHGEAR LINEUP
CYCLOCONVERTER
HECO ELECTRONICS INTERFACE
EIS
SYSTEM DISPLAY PANEL
CHAIR
TELEPHONE & SITE INTERCOM
TABLE TOP
CHAIR
12 FT. HIGH CEILING
DEC WRITER SITE OPERATION TERMINAL
MESA
CDS
DOOR (SINGLE) WITH KEY LOCK (2 PLCS)
TRANSFORMER
8 FT. HIGH CEILING
OUTSIDE LIGHTING (3 PLCS)
P.F. CAPACITOR
AIR CONDITIONER AND HEATER
FIRE EXTINGUISHER (3 PLCS) IN BAY AREA (2 PLCS) IN OFFICE
EMERGENCY LIGHTING (3 PLCS) IN BAY AREA (2 PLCS) IN OFFICE
DOOR (DOUBLE) WITH KEY LOCK AND INSIDE PANIC DEVICE DOOR TO BE SUPPLIED WITH CLOSER ALSO THE CAPABILITY TO MAINTAIN DOOR IN OPEN POSITION

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Figure 9-4 Electrical Equipment Building

The system display panel contains hardware functions for shutdown, manual mode select, and controller reset. Basic operating performance parameters are displayed in engineering units. TV video display and the intercomm are located in the system display panel. An interface for Hawaii Electric Co., which is specifically for the site in Oahu, interfaces with the system display panel and provides command and signal functions to the utility.

The emergency shutdown panel functions independently of the controller. The emergency shutdown panel energizes feather valves that enable the controller to operate hydraulic servo valves. When de-energized, the feather valves cause the ailerons to feather. When the emergency shutdown panel loses one or more input signals, it de-energizes the feather valves for a shutdown that is analogous to a "deadman stick" operation.

A cycloconverter for the variable speed generator subsystem is also shown in Figure 9-4. The converter has a local controller that communicates with the wind turbine controller in the nacelle. This local controller operates the switchgear, controls the converter operation, and detects faults in the converter operation.

9.1.1 CONTROLLER HARDWARE

The controller is an EPTAK 700 series programmable controller, manufactured by the Eagle Signal Division of Gulf-Western. The EPTAK 700 is a micro-processor-based system, which uses the 8080A chip. The main elements are the chassis and power supply and the remote I/O track. The chassis and power supply contains up to 16 working EPTAK control modules. A second chassis contains the additional control modules needed to satisfy the MOD-5A requirements. Each I/O track contains 16 input or output blocks. Seven I/O tracks are used on the MOD-5A, for a total of 112 discrete input/output signals. Analog signals are handled by modules in the chassis.

The basic criteria for the signal interface are: analog signals are 4 to 20 mA, discrete signals are 110 Vac, and serial data communications are 20 mA. The basic requirements for the controller hardware are given in Table 9-1. The specification for the controller hardware is listed in Table 9-2. The specification for the programming equipment and support software is listed in Table 9-3.

TABLE 9-1

CONTROLLER HARDWARE REQUIREMENTS

o INPUT SIGNAL	-	19 ANALOG (4-20 mA)
	-	69 DISCRETE (20 mA, 120Vac)
o OUTPUT SIGNAL	-	6 ANALOG (4-20 mA)
	-	26 DISCRETE (3A or 20A, 120 Vac)
o SERIAL COMMUNICATIONS	-	(2) 20 mA 300 BAUD
	-	(1) 20 mA 1200 BAUD
o MEMORY CAPACITY	-	64K BYTES TOTAL
	-	20K USER PROGRAM
	-	20K RAM
		8K ECL 3 & RAM
		16K INPUT/OUTPUT
o LANGUAGE	-	ECL 3 ASSEMBLY

TABLE 9-2

CONTROLLER HARDWARE SPECIFICATION

CENTRAL PROCESSING UNIT

1	CP711L1	CPU
1	CP719L10102	APU

MEMORY

1	CP773L1 w SL708-0011-XX	16K EXEC
1	CP778L1	12K PROM/4K RAM
1	CP774L1	16K RAM

INTERFACE

3	CP717L1	SERIAL INTERFACE

ERROR DETECTION AND INDICATION PACKAGE

1	CP731L1	WATCHDOG TIMER
1	CP737L1	ERROR INDICATOR

POWER SUPPLY

1	CP761A6010293

CHASSIS

1	CP715L1	CHASSIS INTERFACE
2	CP791A601	CHASSIS
1	CP791-20	CHASSIS
16	CP701L1	FILLER MODULE
1	CP700-90	RESET/AUTO LOAD

DIGITAL I/O

1	CP713L1	I/O MODULE
7	CP714AG	TRACK INTERFACE

ANALOG I/O

2	CP744L1	A/O CONV
3	CP754L101	INPUT MODULE
2	CP756L1	OUTPUT MODULE

CABLES

1	CP711-225	
1	CP713-210	
3	CP717-298	20 FT.
1	CP731-299	10 FT.
1	CP737-299	10 FT.
2	CP754-298	10 FT.
1	CP756-299	10 FT.
1	CP761-215	
1	CPS2000-6100	

PROGRAMMING EQUIPMENT

1	CP786L1	PROG INTERFACE MODULE

TABLE 9-3

PROGRAMMING APPARATUS, PROGRAMMING PACKAGE, AND DOCUMENTATION FOR THE EPTAK HARDWARE

(ONE-TIME EXPENDITURES)

MEMORY		
1	CP774L1	16K RAM
PROGRAMMING PACKAGE FOR CP784CRT PROGRAMMING TERMINAL		
1	SL768-9913-XX	ECL
SOFTWARE LIBRARY (SPECIFY EXECUTIVE D COMPATIBILITY)		
1	SL709-6000-XX	PRINT/KEY IN
1	SL709-6026-XX	IEEE DISPLAY
1	SL709-6027-XX	COMMUNICATIONS
1	SL709-6015-XX	RTC
1	SL709-6024-XX	KEY IN BUFFER/DECODER
PROGRAMMING EQUIPMENT		
1	CP747L1	ANALOG CALIBRATOR
1	CP786A210	INTERFACE MODULE
1	CP780A601	PROM ERASE KIT
1	CP789L1	PROM PROGRAMMER
1	PXXX-72	
1	5005-752	
10	PHT-63	
1	CP783A6	CRT PROGRAMMING SYSTEM

9.1.2 SYSTEM DISPLAY PANEL

The system display panel provides controls for selected operator commands and displays basic operating parameters. The system display panel and the site operator's terminal are located in the office of the electrical equipment building.

The following functions are incorporated into the system display panel:

- emergency shutdown switch
- mode keyswitch
- running time
- video
- intercom
- intrusion alarm
- display

A view of the front panel is shown in Figure 9-5.

The control panel located at the upper left contains the emergency shutdown switch, the mode keyswitch and the running time meter. The video panel located in the left center contains two video TV screens. One camera is located in the nacelle and views the nacelle's interior; the other camera is located outside the equipment building, and views the wind turbine generator. The video control and the intercom are contained on the panel just below the video units. The detailed design of the video control panel has not been completed.

The system display panels are located on the right side. Table 9-4 lists the meter functions incorporated into the display panels. Digital meters are used. The signals are scaled so that the display is in engineering units. Circuit breaker and alarm status indicators are also included on the display panels.

The system display panel includes provisions for an interface between the wind turbine and the utility for an exchange of control and data communications.

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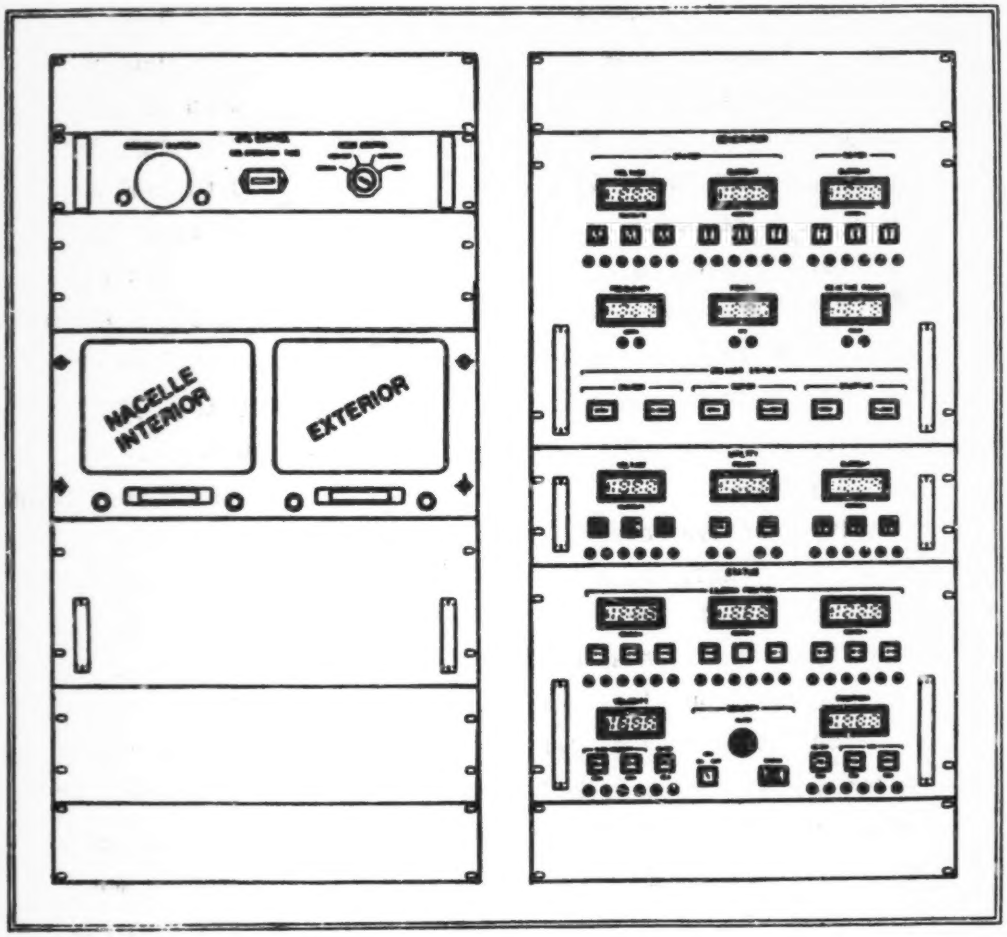
NACELLE INTERIOR
EXTERIOR

Figure 9-5 Front Panel Arrangement of System Display Panel

Table 9-4 System Display Meters

PARAMETER	RANGE
Stator Voltage, Phase A-B	0 to 5.00 kV
Stator Voltage, Phase B-C	0 to 5.00 kV
Stator Voltage, Phase C-A	0 to 5.00 kV
Stator Current, Phase A	0 to 1500 A
Stator Current, Phase B	0 to 1500 A
Stator Current, Phase C	0 to 1500 A
Rotor Current, Phase A	0 to 1500 A
Rotor Current, Phase B	0 to 1500 A
Rotor Current, Phase C	0 to 1500 A
Generator Frequency	55 to 65 Hz
Generator Power	0 to 10 MW
Generator Reactive Power	-2.50 to +2.50 MVAR
Utility Voltage, Phase A-B	0 to 5.00 kV
Utility Voltage, Phase B-C	0 to 5.00 kV
Utility Voltage, Phase C-A	0 to 5.00 kV
Utility Power	-10.00 to + 10.00 MW
Utility Reactive Power	-2.50 to +2.50 MVAR
Utility Current, Phase A	0 to +1500 A
Utility Current, Phase B	0 to +1500 A
Utility Current, Phase C	0 to +1500 A
Aileron Position (1-1, 1-2, 1-3)	-5.0 to +95.0°
Aileron Position (1-4, 2-1)	-5.0 to +95.0°
Aileron Position (2-2, 2-3, 2-4)	-5.0 to +95.0°
Wind Velocity No. 1	0 to 150 mph
Wind Velocity No. 2	0 to 150 mph
Hub Speed	0 to 30.0 rpm
Rotor Position	-180.0 to +180.0°
Yaw Position	-180.0 to +180.0°
Yaw Error	-180.0 to +180.0°

9.1.3 OPERATOR'S TERMINAL

The controller has provisions for two operators terminals. One terminal is located on the site in the ground control enclosure near the base of the tower. The second terminal is remotely located. Voice grade telephone lines link the controller and the remote operator's terminal. These terminals are the interface between the controller and the operator for transmitting operating commands and data summaries. The terminals are "dumb" keyboard printers and the print format and headings are determined by the controller software.

The input commands are shown in Table 9-5. The controller recognizes all commands from the site terminal but does not recognize manual commands from the remote terminal.

The controller issues the same summary of data to both terminals to be printed. The printout format is listed in Table 9-6.

The page heading contains the operating status. Operating data is printed at periodic intervals, and when an alarm or a mode change occurs. All operating data and command inputs are time tagged. A sample printout is shown in Figure 9-6.

The requirements for the terminal are: a standard commercial keyboard-printer with 20 mA serial data interface, 300 BAUD rate, ASCII character format, and modulator-demodulator for telephone line interface.

Table 9-5
Operator Terminal Commands

Function	Command
Operating Mode Commands	
Standby Enable	01
Normal Shutdown	31
Emergency Shutdown	41
Request Terminal Control	51
Enable Terminal Control	61
Power Set Point	2XXX (100kW)
Var Set Point	;XXX
Set Time	8XXYY (XX=Hr., YY=Min.)
Set Date	9XXYY (XX=Month, YY=Day)
Zero Accumulated Energy	71
Rotor Speed Set Point	1XXX (.1 rpm)
Enable Keyboard	[Password]
Disable Keyboard	BYE
Turn Data Output OFF	;0
Turn Data Output ON	;1
Manual mode commands	
Dump Archive	OXX (XX=Line Interval) OXXXY (XXX=Start Line Y=Number of Lines)
Hub Hydraulic Pump	A0, A1 (ON/OFF)
Yaw Hydraulic Pump	B0, B1
Lube Pumps	C0, C1
Shaft Brake	D0, D1
Teeter Brake Low	E0, E1
Teeter Brake Hi	F0, F1
Yaw Brake	G0, G1
Feather Valve 1	H0, H1
Feather Valve 2	I0, I1 (ON/OFF)
Aileron Pair 1	JXX (XX=Degrees)
" Pair 2	KXX (XX=Degrees)
" Pair 3	PXX (XX=Degrees)
" Pair 4	QXX (XX=Degrees)
Turning Gear	L0, L1 (ON/OFF)
Emergency Shutdown	M0, M1 (ON/OFF)
Yaw Position	NXYY (X=+=CW Y=-=CCW YY=Seconds Time of Correction)

Table 9-6
Data Summary Information

Function	Units
Status Printout - Page Heading	
Date	Month, Day
Time	Hour, Min, Sec.
Control	Operating Terminal recognized by Controller for input commands (site, remote)
Energy Yesterday	MWH
Energy to Date	GWH - Month, Day
Machine Availability	%
Power Set Point	MW
VAR Set Point	MVAR
Operating Summary - Periodic 1-line output	
Time	Hr., Min., Sec.
Alarm	ID Number (0 to 255)
Wind Velocity	mph
Power	MW
Energy for Date	MWH
Operating Mode	(LO, SBI, SBE, SU, RMP, PWR, NSD)

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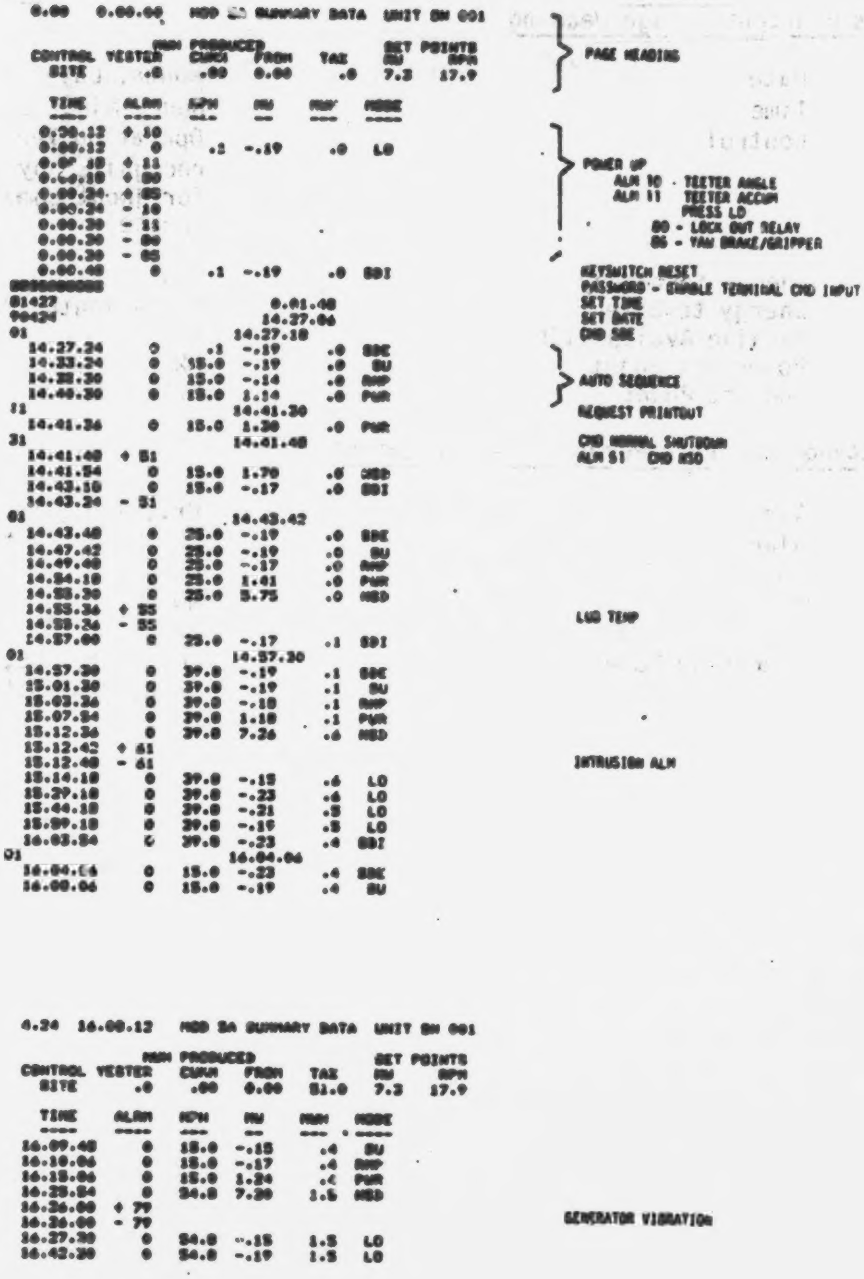

```
0.00   0.00.00   MOD 5A SUMMARY DATA   UNIT SN 001          PAGE HEADING

              KWH PRODUCED                SET POINTS
CONTROL  YESTER   CUMM    FROM    TAX     KW     RPM
  SITE       .0    .00    0.00     .0    7.3    17.9

  TIME     ALRM    MPH     KW     KWH    MODE
  ----     ----    ---     --     ---    ----
 0.00.12   + 10                                             POWER UP
 0.00.12      0     .1   -.19      .0    LO                   ALM 10 - TEETER ANGLE
 0.00.18   + 11                                               ALM 11   TEETER ACCUM
 0.00.18   + 80                                                          PRESS LO
 0.00.24   + 85                                                    80 - LOCK OUT RELAY
 0.00.24   - 10                                                    85 - YAW BRAKE/GRIPPER
 0.00.30   - 11
 0.00.30   - 80
 0.00.30   - 85
 0.00.48      0     .1   -.19      .0   SDI                 KEYSWITCH RESET
[redacted]                                                  PASSWORD - ENABLE TERMINAL CMD INPUT
81427                    0.01.48                            SET TIME
90424                   14.27.06                            SET DATE
01                     14.27.18                             CMD SDE
  14.27.24      0     .1   -.19      .0   SDE
  14.33.24      0   15.0   -.19      .0    SU               AUTO SEQUENCE
  14.38.30      0   15.0   -.14      .0   RMP
  14.40.30      0   15.0   1.14      .0   PWR
11                     14.41.30                             REQUEST PRINTOUT
  14.41.36      0   15.0   1.30      .0   PWR
31                     14.41.48                             CMD NORMAL SHUTDOWN
  14.41.48   + 51                                           ALM 51   CMD NSD
  14.41.54      0   15.0   1.70      .0   NSD
  14.43.18      0   15.0   -.17      .0   SDI
  14.43.24   - 51
01                     14.43.42
  14.43.48      0   25.0   -.19      .0   SDE
  14.47.42      0   25.0   -.19      .0    SU
  14.49.48      0   25.0   -.17      .0   RMP
  14.54.18      0   25.0   1.41      .0   PWR
  14.55.30      0   25.0   5.75      .0   HSD
  14.55.36   + 55                                           LSD TEMP
  14.55.36   - 55
  14.57.00      0   25.0   -.17      .1   SDI
01                     14.57.30
  14.57.30      0   39.0   -.19      .1   SDE
  15.01.30      0   39.0   -.19      .1    SU
  15.03.36      0   39.0   -.18      .1   RMP
  15.07.54      0   39.0   1.18      .1   PWR
  15.12.36      0   39.0   7.26      .6   HSD
  15.12.42   + 61                                           INTRUSION ALM
  15.12.48   - 61
  15.14.18      0   39.0   -.15      .6    LO
  15.29.18      0   39.0   -.23      .6    LO
  15.44.18      0   39.0   -.21      .5    LO
  15.59.18      0   39.0   -.19      .5    LO
  16.03.54      0   39.0   -.23      .4   SDI
01                     16.04.06
  16.04.14      0   15.0   -.23      .4   SDE
  16.08.06      0   15.0   -.19      .4    SU



4.24  16.09.12   MOD 5A SUMMARY DATA   UNIT SN 001

              KWH PRODUCED                SET POINTS
CONTROL  YESTER   CUMM    FROM    TAX     KW     RPM
  SITE       .0    .00    0.00   51.0    7.3    17.9

  TIME     ALRM    MPH     KW     KWH    MODE
  ----     ----    ---     --     ---    ----
16.09.48      0   15.0   -.15      .4    SU
16.10.06      0   15.0   -.17      .4   RMP
16.15.06      0   15.0   1.24      .4   PWR
16.25.54      0   24.0   7.20     1.5   HSD
16.26.00   + 79                                             GENERATOR VIBRATION
16.26.00   - 79
16.27.30      0   24.0   -.15     1.5    LO
16.42.30      0   24.0   -.19     1.5    LO
```

Figure 9-6. Sample Operator Terminal Printout

9.1.4 EMERGENCY SHUTDOWN PANEL

The emergency shutdown (ESD) panel uses hardware logic that is independent of the controller to stop the wind turbine generator. A "deadman" approach is used for the emergency shutdown logic. Energized relays close contacts that hold hydraulic solenoid valves in an energized position. With these valves energized, the aileron control is allowed to operate. When the emergency shutdown panel loses the input signals defined below, the logic relays de-energize, opening the contacts that de-energize the hydraulic solenoid valves, and initiating a delayed application of the rotor-stopping brakes. When these valves de-energize, the aileron control system feathers. A logic diagram of the emergency shutdown panel is shown in Figure 9-7. A schematic of the emergency shutdown and solenoid circuits is shown in Figure 9-8.

The signal inputs are:

- Ground Emergency Stop Switch
- Generator Overspeed
- Nacelle Emergency Stop Switch
- Rotor Overspeed
- Watch Dog Timer (Controller)
- ESD Enable (pulse)
- Feather Valve A1 Enable
- Feather Valve A2 Enable

The emergency shutdown panel provides the following outputs:

- Feather Valve (A1) Cmd
- Feather Valve (A2) Cmd
- ESD Ready Signal
- Feather Valve (A1) Status
- Feather VAlve (A2) Status
- Rotor Brake Cmd

The "ESD ready" signal is issued when all inputs except the feather valve (A1) and (A2) enable commands are in their normal operational state. This condition indicates that the panel is ready to operate.

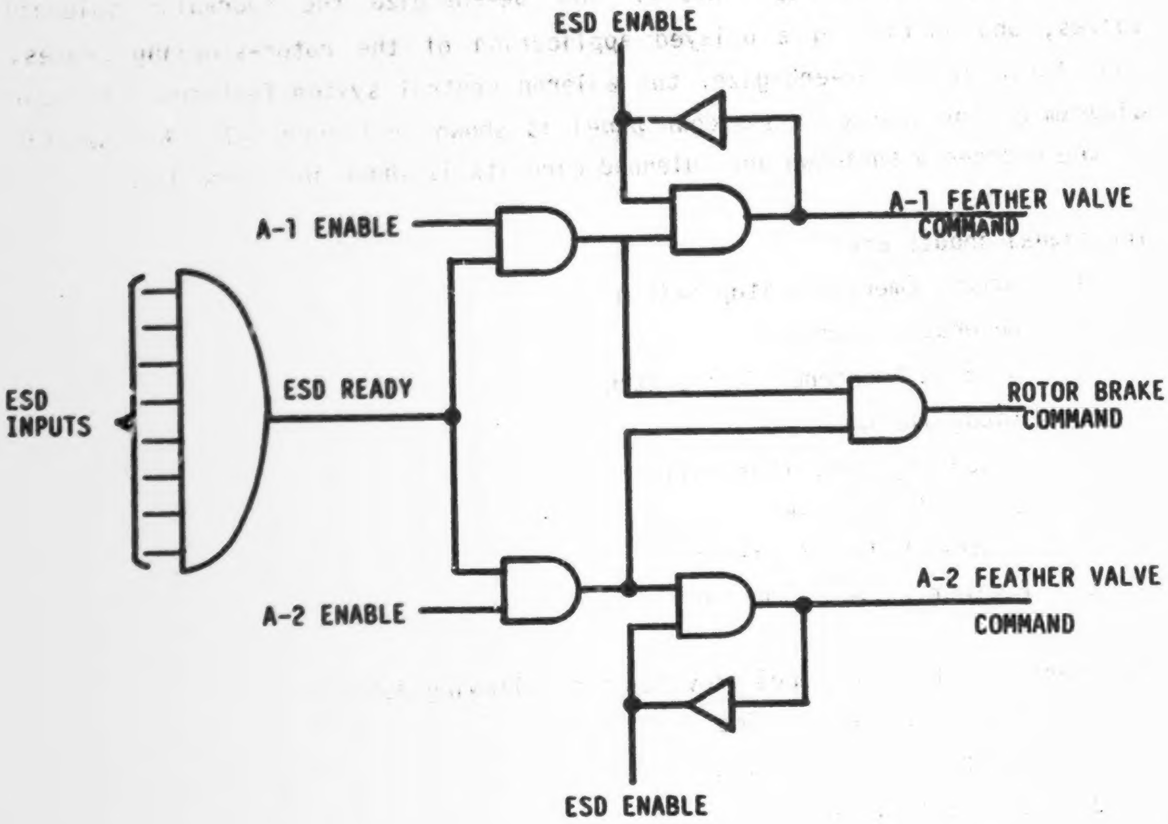
ESD ENABLE
A-1 ENABLE
A-1 FEATHER VALVE COMMAND
ESD INPUTS
ESD READY
ROTOR BRAKE COMMAND
A-2 ENABLE
A-2 FEATHER VALVE COMMAND
ESD ENABLE

Figure 9-7 Logic Diagram - Emergency Shutdown Panel

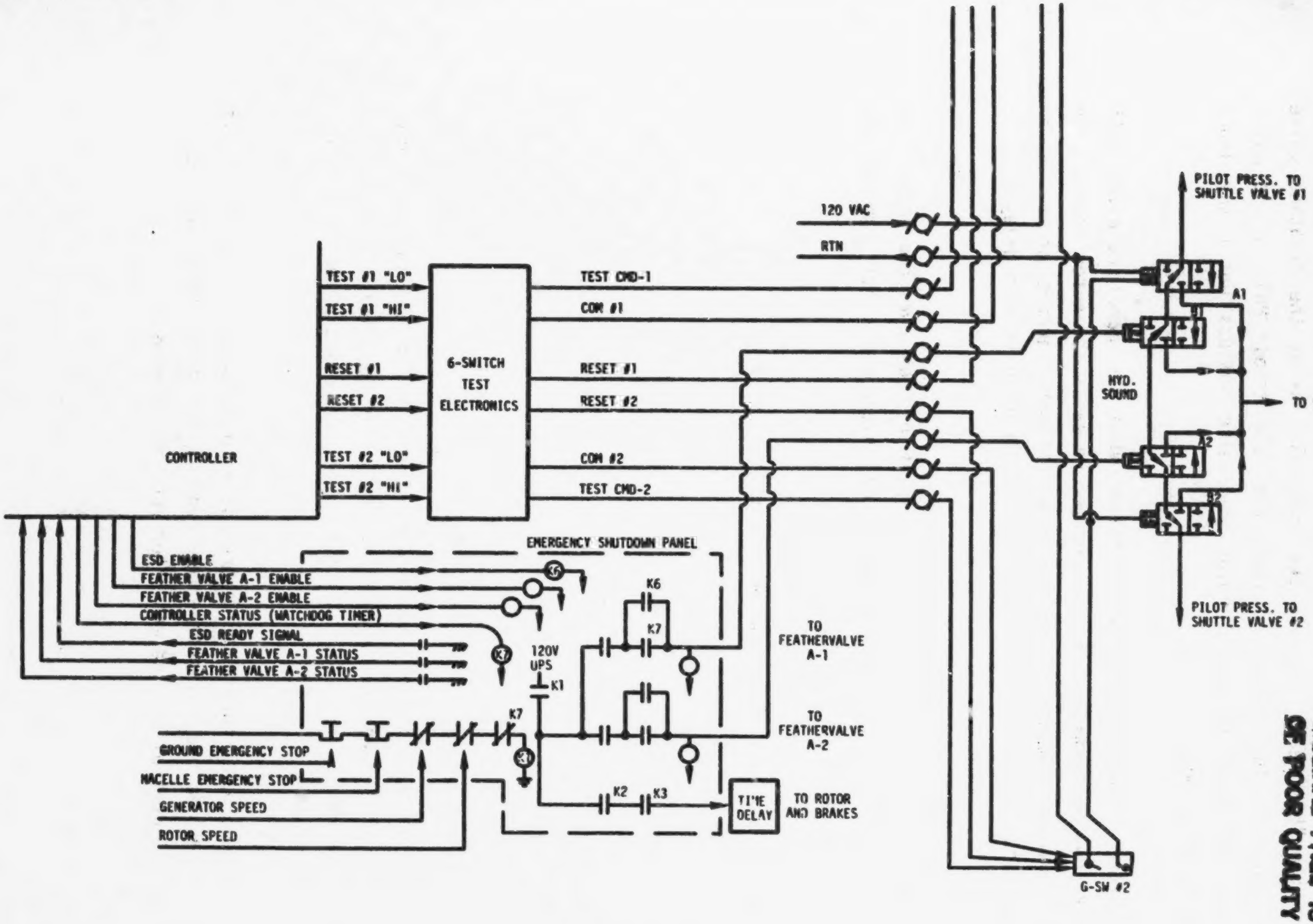
PILOT PRESS. TO SHUTTLE VALVE #1
120 VAC
RTN
A1
TEST #1 "LO"
TEST #1 "HI"
TEST CMD-1
COM #1
6-SWITCH TEST ELECTRONICS
RESET #1
RESET #2
RESET #1
RESET #2
HYD. SOUND
TO SUMP
A2
CONTROLLER
TEST #2 "LO"
TEST #2 "HI"
COM #2
TEST CMD-2
B2
EMERGENCY SHUTDOWN PANEL
ESD ENABLE
FEATHER VALVE A-1 ENABLE
FEATHER VALVE A-2 ENABLE
CONTROLLER STATUS (WATCHDOG TIMER)
ESD READY SIGNAL
FEATHER VALVE A-1 STATUS
FEATHER VALVE A-2 STATUS
K6
K7
120V UPS
K1
TO FEATHERVALVE A-1
PILOT PRESS. TO SHUTTLE VALVE #2
K7
TO FEATHERVALVE A-2
GROUND EMERGENCY STOP
NACELLE EMERGENCY STOP
GENERATOR SPEED
ROTOR SPEED
K2
K3
TIME DELAY
TO ROTOR AND BRAKES
G-SW #2

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Figure 9-8 Schematic Diagram of the Emergency Shutdown

The feather valve output signals are issued after a sequence in which the panel sends the "ESD ready" signal, the controller sends the "feather valve enable" signals, and the controller sends the "ESD Enable Pulse". The pulse operates as a one-shot latch and holds the valve outputs until any input change removes latch power.

The rotor brake command circuit is energized when the panel receives both feather valve enable commands. The controller releases the rotor brakes with a separate command. De-energizing the brake command circuit occurs on an emergency shutdown operation and causes brake application after a delay.

9.1.5 CYCLOCONVERTER CONTROL

The cycloconverter control is an integral part of the cycloconverter. It interfaces with the controller via hard wire interconnect for command and control functions.

The basic operating modes of the cycloconverter control are:

Initialization
Motoring (singly excited machine)
Synchronization
Torque regulation
Reactive power regulation
Shutdown
Fault monitoring

Initialization

The initialization mode occurs when power is applied to the cycloconverter control. All outputs power-up to an off-state. The thyristor firing control is set to a non-conducting state. Control power is applied before the 4160 V line power is connected.

Next, the control checks for faults appropriate to a non-operating state. If there are no faults the cycloconverter control sends a "converter ready" signal to the WTG controller, and waits for further commands.

Motoring, Singly Excited

When the WTG controller finds conditions are satisfactory for start-up, it sends "turbine ready" and "start/motor" commands. When the converter receives a "start/motor" command, it performs the following functions:

a) checks for the "turbine ready" signal to validate the "start/motor" signal
b) turns on cooling fan and checks air flow
c) sends "stator tie trip" signal and checks stator tie position is open
d) sends "stator short trip" signal and checks stator short position is open
e) sends "stator short close" signal and checks stator short position is closed. The control will then send a "speed" reference signal to the converter.
f) uses the torque/speed analog reference, with protective functions of overriding current limit, rotor voltage/frequency limit, and frequency limit, to regulate the generator speed between 0 and approximately 300 rpm
g) at the upper end of the permissible motoring speed range, the converter waits for the start/motor command to be removed
h) when the start/motor command is removed by the WTG controller, the converter slues rotor current to zero, independently of the torque/speed reference, then
i) sends the stator short open command and checks that the stator short position is open, then
j) stays in a non-conducting mode and waits for a synchronize/generate command. The WTG controller accelerates the generator shaft speed to the generating range (960 to 1440 rpm).

NOTE: The WTG controller uses a "stator short position" signal and a turbine speed signal to verify the converter control response.

Synchronization

When the converter control receives a "sync/generate" signal from the WTG controller, it performs the following functions:

a) checks for generator speed between 960 and 1440 rpm. If the speed is outside this range, the converter waits until the speed reaches this range.
b) using the stator voltage and bus voltage, which it reads from the secondary windings of the instrument transformers, the converter controls thyristor firing to cause the induced stator voltage to match the bus voltage in amplitude, frequency, phase, and phase sequence.
c) when the voltages match, the converter sends the stator tie close signal and checks that the stator tie position is closed.
d) after the stator tie is closed, the converter operates simultaneously in both torque regulation and reactive power regulation modes.

Torque Regulation

a) The WTG controller sends an analog torque reference to the converter. Using the analog torque/speed reference, the converter regulates air gap torque as indicated by stator real power. The stator power feedback is computed using stator voltage and stator current instrument transformer signals.

b) If the reference torque temporarily exceeds the rated capability of the system, the converter automatically limits torque to 110% of rated capability.
c) The converter continues operation until the sync/generate command is removed by the controller.

The torque regulation achieves ±1% of the rated air gap torque within one second of a 20% step change in reference with shaft slue rates of up to 0.05 pu/second relative to the synchronous speed. The torque signal range is -20% to +120% of the rated torque.

Reactive Power Regulation

a) The control also sends a var reference signal. Using this Var/Volt analog reference, the converter will regulate the 4160 V bus reactive power. The reactive power feedback is computed using the bus voltage and bus current instrument transformer signals.
b) If the reference Var value exceeds the system's capability because of rotor circuit kVA or stability limits, automatically limits Var regulation to maintain torque regulation. Simultaneous regulation is required, but torque regulation has higher priority when limiting conditions are reached.
c) Continues operation until the sync/generate command is removed by the WTG controller.

Reactive power regulation achieves ±1% of the system rating within one second after a 20% step change in reference, with shaft slue rates of up to 0.05 pu/second relative to synchronous speed. The voltage control is an optional regulation mode, which uses the bus voltage as feedback. The reference signal ranges are ±10% of 7500 kVA or 4160 V, depending on the mode.

Shutdown

Shutdown is initially the same as the generating condition. The torque/speed reference is ramped up by the WTG controller to the maximum value at 5% per second. The WTG controller uses the aerodynamic control surfaces to reduce the shaft speed.

a) When the generator speed reaches approximately 980 rpm, the WTG controller ramps the torque/speed reference to zero at 5% per second, while externally regulating turbine speed, then
b) the WTG controller removes the sync/generate command.
c) When the sync/generate command is removed, the converter control automatically regulates the stator power and stator Vars to zero, regardless of analog reference values.
d) When stator power and stator Vars are below 5% of the rating, the converter control sends a stator tie open command and checks that the stator tie position is open.
e) The converter is brought to a non-conducting state
f) The WTG controller brings the generator speed to zero.

g) When the speed is below 60 rpm and when the converter temperature is acceptable or after a time delay, the cooling fans are turned off
h) The converter waits for a start/motor command from the WTG controller.

Fault Monitoring

The converter control monitors converter and turbine operation for at least the following faults:

a) overpower - stator, motoring or generating
b) overpower - rotor, motoring or generating
c) converter overcurrent
d) bridge fault
e) control malfunction
f) control power loss
g) cooling air loss
h) phase unbalance
i) overspeed beyond 1500 rpm
j) turbine control ready signal
k) stator over/under voltage
l) uncommanded stator tie breaker trip

For items i) and j), the converter control automatically ramps the torque reference used for torque regulation to the maximum value until the generator speed is below 960 rpm, then continues as if it were in the shutdown mode after a sync/generate command was removed. This provides maximum backtorque in case of overspeed or WTG controller malfunction.

For item g), the converter control turns on the second cooling fan and if the air flow recovers, the converter control continues operation. This response maintains the availability of the wind turbine generator.

For all faults but g), the converter control removes the "converter ready" signal to the turbine control, which starts the shutdown procedure. If a cooling air loss is not cleared by the second fan, then the "converter ready" signal is removed after a delay. For permanent faults, which require maintenance, the converter control opens the stator tie circuit breaker via the lockout relay.

9.2 CONTROL SOFTWARE

The control software provided with the EPTAK system is the ECL 3/Executive D. The executive D software processes system interrupts, power-up and -down operation, error detection, arithmetic functions, data conversions, and ECL3 control functions. The standard ECL3 instructions are:

- logic
- print/keyin
- transfer of control
- arithmetic

The logic instructions are:

- load
- compliment
- store
- AND
- compliment AND
- OR
- compliment OR
- exclusive OR
- compliment exclusive OR
- compare
- binary invert
- invert
- no operation
- load double accumulator with address
- load SP1 and SP2 with address.

The print instruction commands transmission of character-string information to a peripheral device. The keyin instruction allows the input of characters from a keyboard.

Transfer of control functions are:

- unconditional jump
- jump on equal
- jump if less than
- subroutine call
- return from subroutine

Arithmetic functions are:

- load double accumulator
- store double accumulator
- add double accumulator
- multiply double accumulator
- divide double accumulator

The EPTAK system can be programmed using 8080 assembly language instructions.

The user application software was generated by GE and consists of the following:

- o structure declaration
- o cold start
- o executive
- o main program
- o vendor software

The main program of the controller is divided into the following software modules:

- o Input Signal Manager (ISM)
- o Data Processing
- o Mode Logic
- o Data Archive
- o Power Generation
- o Manual
- o Communication
    - - Remote Terminal
    - - Site Terminal
    - - Control Data System (CDS)
- o Start-up
- o Ramp
- o Yaw
- o Alarm
- o Normal/Emergency Shutdown
- o Rotor Hydraulic Pump Module
- o Output Signal Management (OSM)
- o Memory Test (background)

9.2.1 STRUCTURE DECLARATION

The structure declaration defines the labels required to use the executive D program functions. The declare statements are located at the beginning of the user program and consist of the following:

- o equate memory and input/output (EQU)
- o real time clock (ARTX)
- o analog input (AIS)
- o user RAM (EQUR)
- o text statement (TXT)
- o user print/keyin (PK)
- o user keyin (KEYIN)

9.2.2 COLD START

Cold start is executed once, at power up, to initialize the system. The functions of cold start are:

- set the activation flags for full time modules
  - alarm
  - controls data system data output
  - operator's terminal data output
- initialize output commands
  - aileron at feather (90°)
  - yaw gripper and brake ON
  - lockout relay
- initialize variable parameters
  - zero the counters
  - archive sample rate
  - proportional gains and integration constants
  - aileron output command rate limit
  - data conversion constants
- set default configuration
  - site terminal control
  - operators terminals connected
  - lockout mode
  - ramp speed limit
  - HI & LO speed reference
  - power set point

9.2.3 EXECUTIVE

The executive module controls execution of the main program modules. A flow chart of the executive module is shown in Figure 9-9.

Each main program module has several submodules called segments. A RAM location is used as an activation flag for each module and another RAM location is used as a segment counter. The activation flag is used by executive to execute the corresponding module. If the module is activated, then the segment counter is used to decide which segment or part of the module to call.

The executive is initiated by a timer at intervals of 100 msec and addresses the main program modules in sequence. The ISM, OSM, data processing, mode and data communications modules are called continuously by the executive. The yaw and data archive modules are called continuously by the executive if the controller is in the automatic run mode sequence. Start-up, ramp, power generation, shutdown, and standby/enable are automatic run sequence modules and are called as determined by the mode module. The standby/inhibit, lockout, and manual modes are determined by operator command. The standby/inhibit and lockout modes are also generated after a safety shutdown.

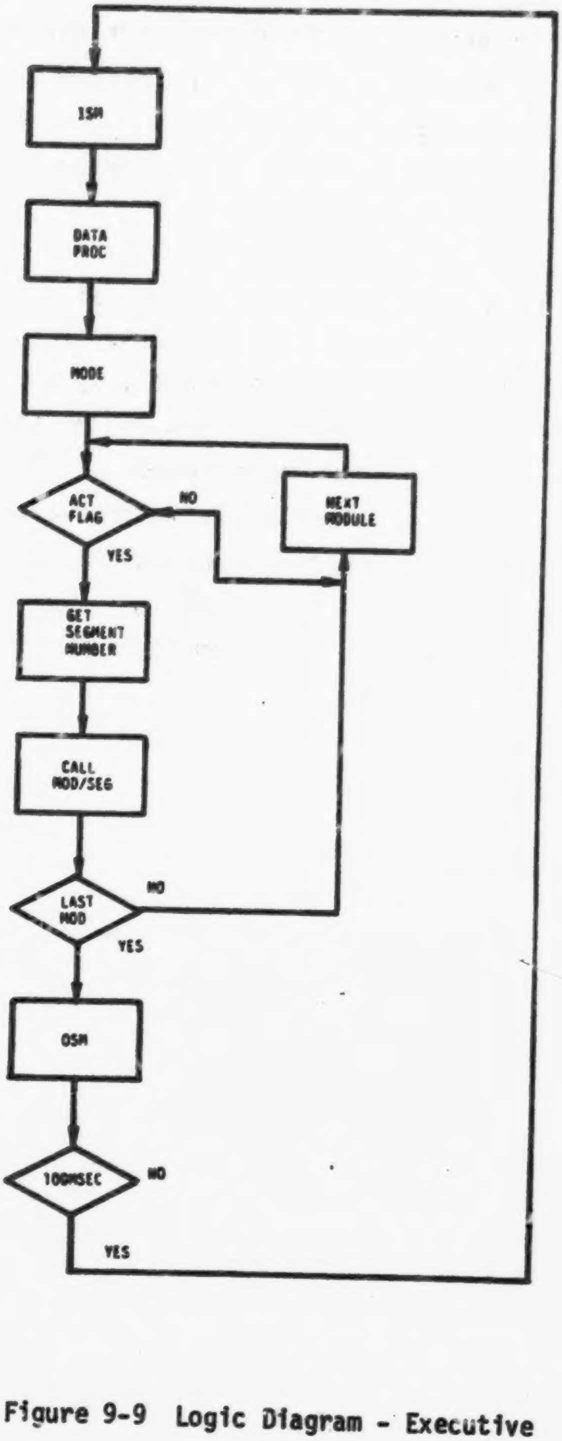
ISM
DATA PROC
MODE
ACT FLAG
NO
YES
NEXT MODULE
GET SEGMENT NUMBER
CALL MOD/SEG
LAST MOD
NO
YES
OSM
100MSEC
NO
YES

Figure 9-9 Logic Diagram - Executive

9.2.4 MAIN PROGRAM

The main program of the controller comprises the following modules:

- input signal manager (ISM)
- data processor
- mode logic
- data archive
- power generator
- manual
- communications
    - remote terminal
    - site terminal
    - controls data system (CDS)
- start-up
- ramp
- yaw
- alarm
- shutdown
- rotor hydraulic pump
- output signal manager (OSM)
- background memory test

Figure 9-10 shows the sequence of events in the automatic operating mode, which includes start-up, ramp/sync, power generate and shutdown. Figure 9-11 shows the control of aileron position and generator torque during power generate operation.

9.2.4.1 Input Signal Management (ISM)

The ECL executive controls the input and output of signals to and from the EPTAK system. It is transparent to the user application software. The input signal manager transfers the signals read in by the ECL executive into user RAM throughout the user executive cycle.

9.2.4.2 Data Processing

The data processing module calculates signal averages, data for output, and discrete signal packing.

The calculations are:

- energy produced yesterday and today
- the machine's mechanical availability yesterday and today. The mechanical availability is defined as:

$$1 - \frac{\text{time in lockout mode}}{\text{total elapsed time}}$$

- aileron angle correction for pairs of ailerons
  corrected angle = (angle reading - bias)*slope

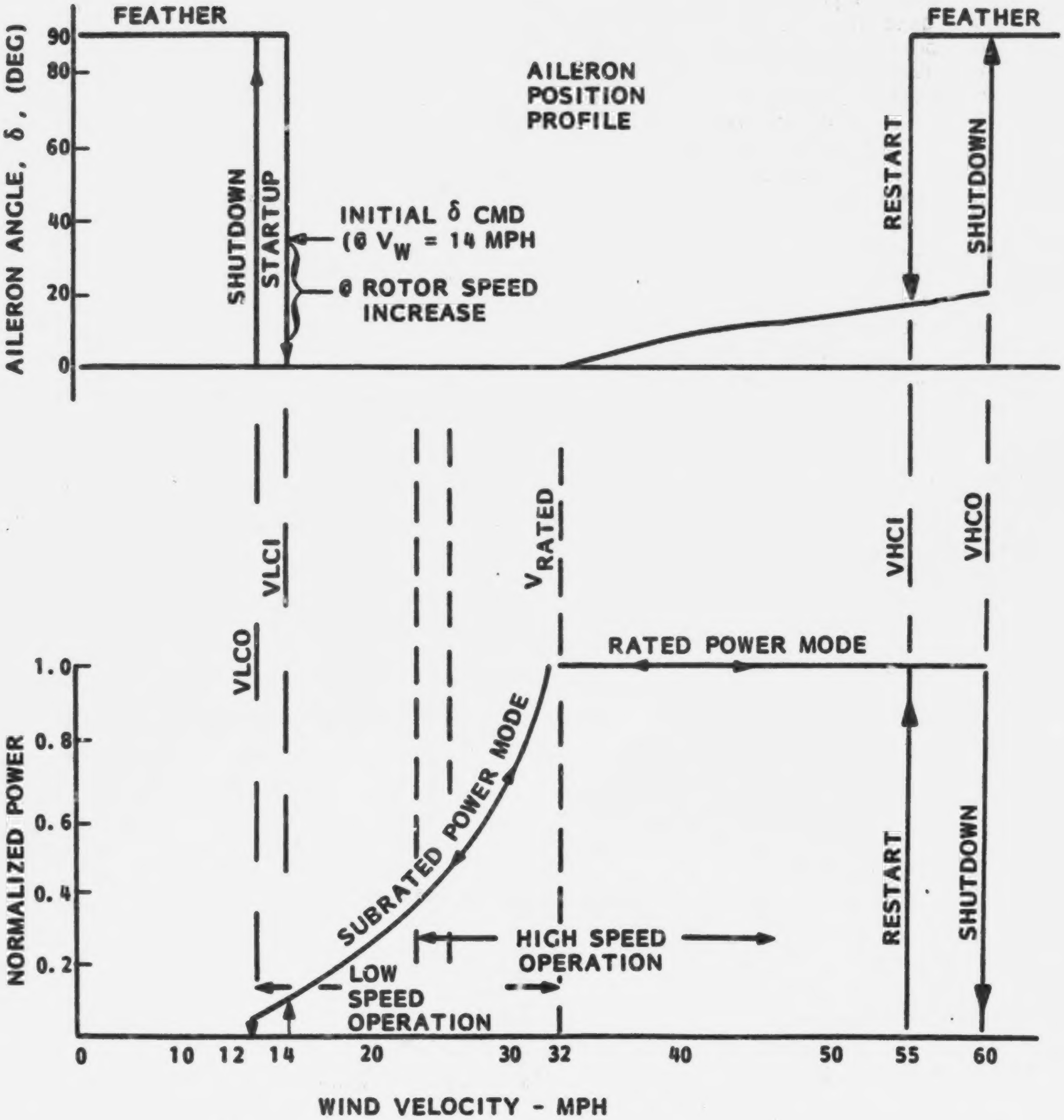

Figure 9-10 Aileron Profile and Operating Modes as a Function of Wind Speed

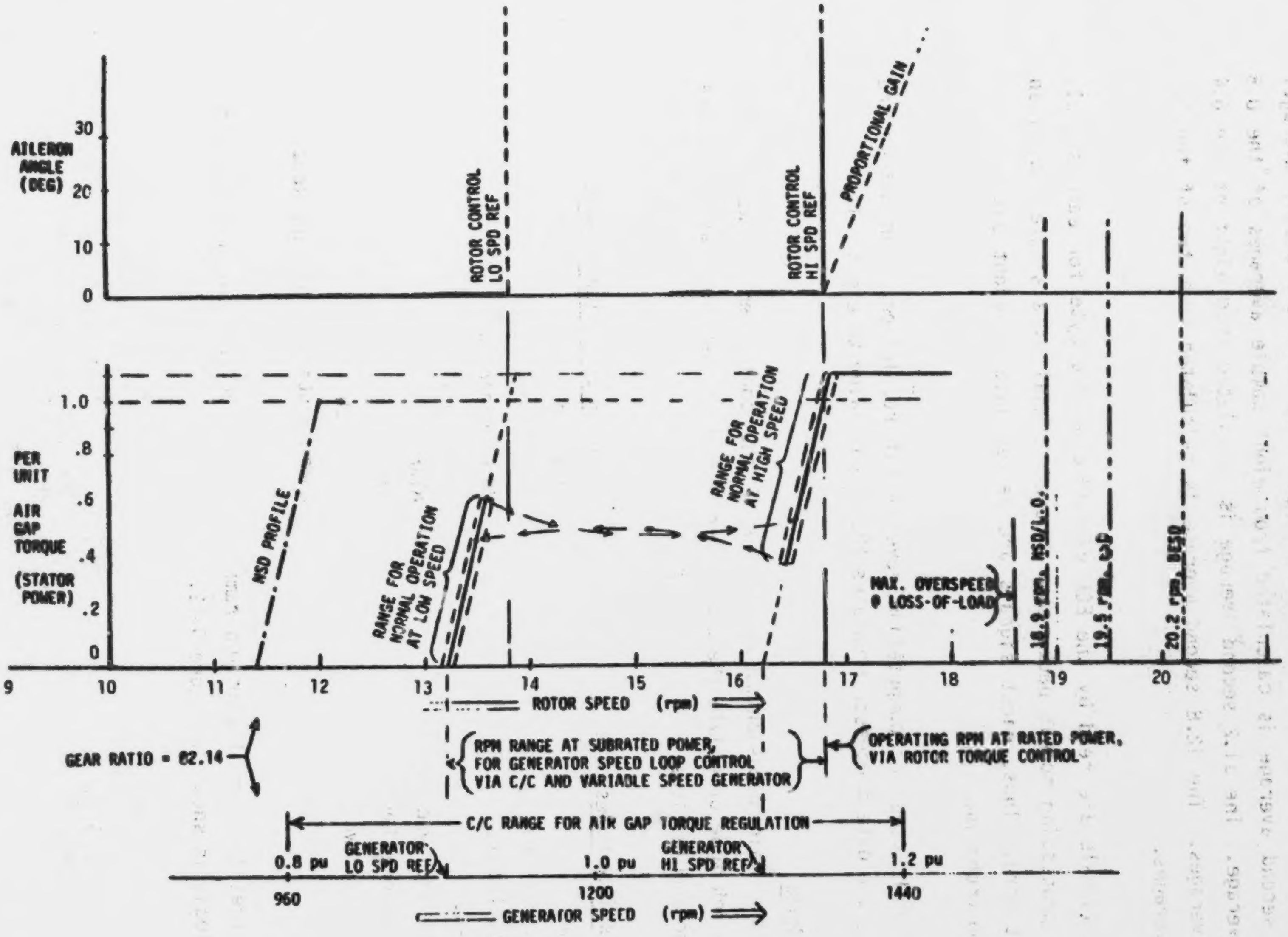

Figure 9-11 Power Generation Operating Regions

Signals are time averaged by averaging a set of eight readings taken every 0.1 second, and calculating longer time averages from this 0.8 second average. The 6.4 second average is calculated from eight sample averages of the 0.8 second average. The 51.2 second average is calculated from eight of the 6.4 second averages. The 12.8 second average is calculated from two of the 6.4 second averages.

Discrete signals are read by the ECL executive as one byte for each signal. The data processing module packs each discrete signal as a single bit in an eight bit word. Thus, eight signals are packed into an eight bit word for output and archiving.

Analog signals used for computation have 12 bit resolution. For output and archiving, the data processor truncates the 12 bit value to eight bits.

9.2.4.3 Mode

MODE is the main decision-making module of the controller software. MODE decides which mode or module the controller should be executing, and activates the proper module flags.

Possible Modes	Modules Scheduled by MODE
Lockout	Start-up
Standby Inhibit	Ramp Up and Sync
Standby Enable	Power Generation
Start-up	Normal Shutdown
Ramp Up and Sync	Alarms
Power Generation	Yaw
Normal Shutdown	Data Archiving
	Communications, Site and Remote

Mode sequences the normal start-up ramp/sync, power generation, and shutdown. The mode logic is shown in Figure 9-12.

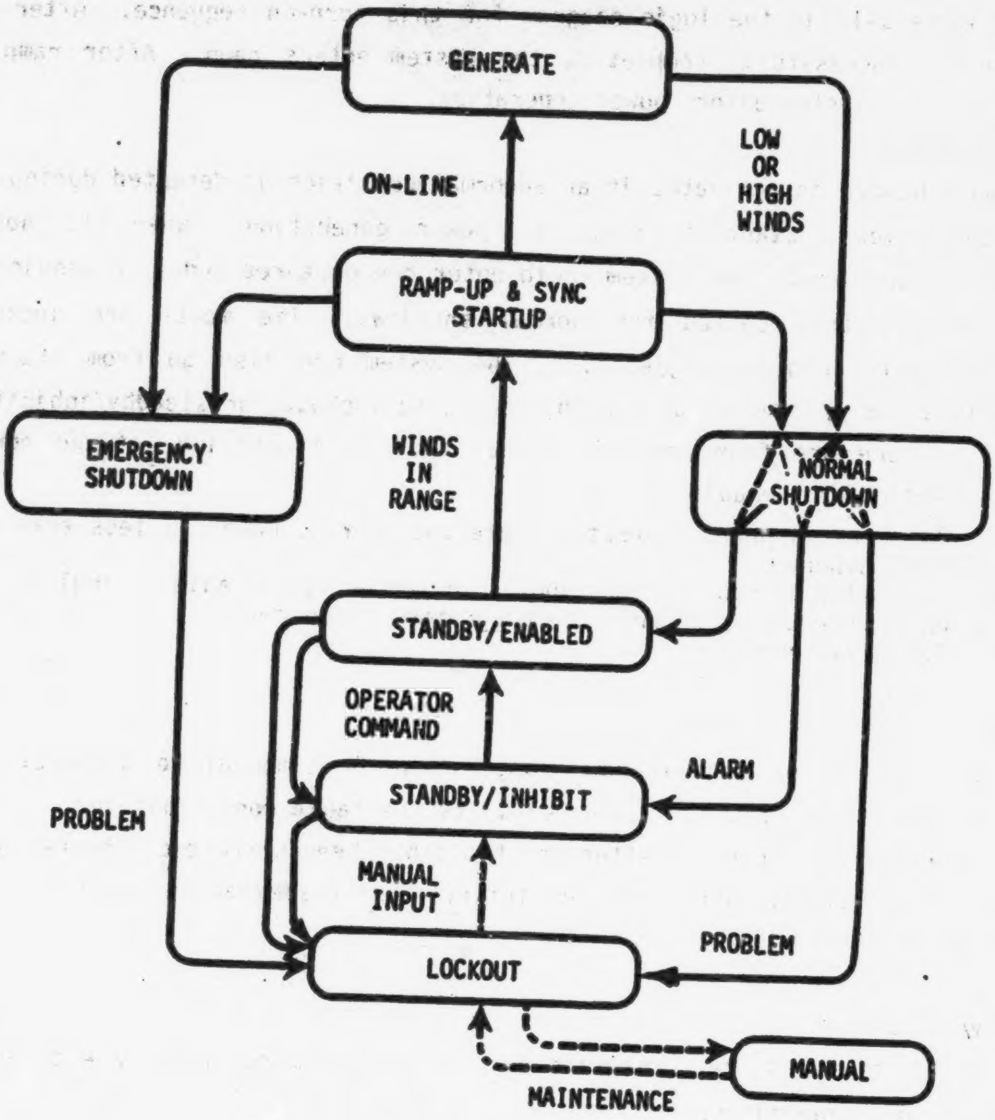
GENERATE
ON-LINE
LOW OR HIGH WINDS
RAMP-UP & SYNC STARTUP
EMERGENCY SHUTDOWN
WINDS IN RANGE
NORMAL SHUTDOWN
STANDBY/ENABLED
OPERATOR COMMAND
ALARM
STANDBY/INHIBIT
PROBLEM
MANUAL INPUT
LOCKOUT
PROBLEM
MANUAL
MAINTENANCE

Figure 9-12 Control System Mode Logic

Lockout is the default and initial mode. To exit lockout and enter standby/inhibit, the keyswitch on the system display panel must be switched to automatic. To exit standby/inhibit and enter standby/enable, an enable command must be generated from the site or remote terminal. The system will go to start-up when the 5 minute wind speed average is between 14 mph and 55 mph. Figure 9-13 is the logic diagram for this turn-on sequence. After the start-up is successfully completed, the system enters ramp. After ramp is completed, the system enters power generation.

A normal shutdown is activated if an abnormal condition is detected during any operation: mode, start-up, ramp, or power generation. When the normal shutdown is completed, the system could enter one of three modes, depending on the condition that caused the normal shutdown. The modes are lockout, standby/inhibit, and standby/enable. The system can also go from standby/enable to standby/inhibit, or standby/enable to lockout, or standby/inhibit to lockout. There are four conditions that cause a transition between normal shutdown and standby enable:

1. low wind in power generate, where the average power is less than zero for 5 minutes
2. high wind in power generation, as detected by the aileron angle
3. excessive excursion from the programmed speed ramp
4. large yaw error

Lockout

Lockout is called on initial power up, change from manual to automatic, or after a second level fault. Table 9-7 lists the fault conditions that cause a normal shutdown to lockout. After the fault has been corrected, the keyswitch on the System Display Panel will reinitialize the system and place the system in the standby/inhibit mode.

Standby/Inhibit

This mode is a hold state. The wind turbine is ready, no faults are detected, but start-up is inhibited.

The standby/inhibit mode can be entered from lockout, via the system display panel keyswitch. It can also be entered at the conclusion of a normal shutdown initiated by a command from the site or remote terminal or by certain recoverable alarm conditions listed in Table 9-8.

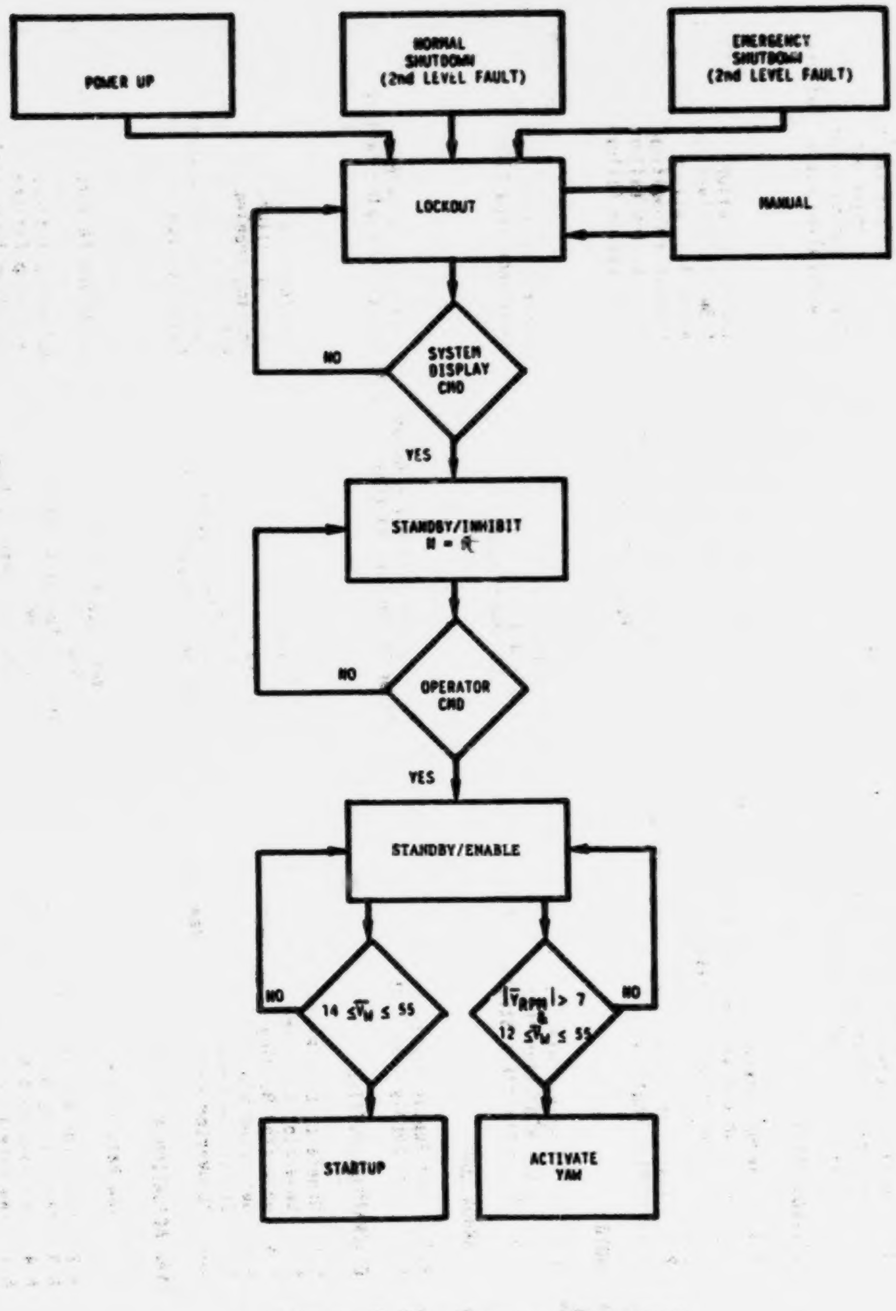
POWER UP
NORMAL SHUTDOWN (2nd LEVEL FAULT)
EMERGENCY SHUTDOWN (2nd LEVEL FAULT)
LOCKOUT
MANUAL
NO
SYSTEM DISPLAY CMD
YES
STANDBY/INHIBIT
NO
OPERATOR CMD
YES
STANDBY/ENABLE
NO
$14 \le \bar{V}_W \le 55$
$|\bar{Y}_{RPM}| > 7$ & $12 \le \bar{V}_W \le 55$
NO
STARTUP
ACTIVATE YAW

Figure 9-13 Turn-on Sequence

Table 9-7

"Second Level Fault" Shutdowns → (NSD to Lockout)

	Condition	Trigger Condition	Expected Cause
I.	GENERAL CS		
1.1	Intrusion Alarm	- event -	Unauthorized entry
1.2	Emergency Shutdown Panel Failure	Signal from ESP	Relay circuit fault
1.3	Control Enclosure Cabinet Temp "HI-HI"	$T > 122°F$	Heat exchanger out
1.4	Rotor/Generator Speed Mismatch	$\|N_R - N_G\| > 0.2$ rpm	Speed sensing error
1.5	C.E.C. Temp. Out-of-Range	$T > 60°C$ or $T < -10°C$	Heat/Cooling Equip. Failure
II.	AILERON ACTUATION & TEETER BRAKE		
2.1	Aileron Emergency Feather Accum. Press."LO"	$\Delta P < 2000$ psi	Leak/pump failure
2.2	Aileron Cmd vs. Position Mismatch	$\|\delta_{cmd}-\delta_{11}\| > 10°$	G-Switch Activation
2.3	Aileron Deflection Mismatch	$\|\delta_{1x}-\delta_{2x}\| > 5°$	Actuation failure
2.4	Teeter High Force (HF) Brakes "ON"	Angle > 5° (See 3.3.5)	Unbalance condition
2.5	Teeter HF Brakes Stay "ON" @ Ramp-up	HF = "ON" and $N_R > 12.5$ rpm	Brake system failure
2.6	Teeter Angle Large	Analog Signal, $\|\alpha_T\| > 6.5°$	Brake system failure
III.	ROTOR		
3.1	Rotor Speed "HI"	$N_R \geq 18.9$ rpm	Control failure
3.2	Rotor Vibration "HI"	Vib ≥ 0.1 g	Unbalance condition
3.3	Rotor Structure Strain "HI"	TBD Overstrain	
IV.	GEARBOX LUBE		
4.1	Lube Supply Pressure "LO"	"2-of-3" sensors @ $P < 60$ psi	Leak/pump failure
4.2	Lube Supply Temp. "HI"	"2-of-3" sensors HI (See 3.3.6.3)	Heater or cooler failure
V.	GENERATOR/CONVERTER		
5.1	Generator Lube Press. "LO"	P < psi	Leak/pump failure
5.2	Generator Lube Temp. "HI"	$T > 250°F$	Cooling failure
5.3	Generator Bearing Temp. "HI"	$T > 275°F$	Bearing problem
5.4	Generator Vib. "HI"	Vib > 0.1 g	Unbalance
5.5	Stator Tie Breaker Trip	Lock Out Relay Tripped	(See 3.3.9 discussion)
5.6	"Converter Ready" Signal Removed	Event per converter control	Converter fault
VI.	YAW ACTUATION AND ROTOR BRAKES		
6.1	Yaw Rate Correction Low	Low Yaw rate @ startup (See 3.3.1.1.2)	Actuation failure
6.2	Yaw Error Remains High	$\|Y_e\| > 7°$ for $\Delta t = 5$ min.	Actuation failure
6.3	Yaw Holding Brake Status Fault	Status ≠ Cmd	Leak/pump failure
6.4	Yaw Holding & Motive Brakes OFF	P < 2000 psi, both systems	Operating logic failure
6.5	Yaw Rate Excessively High	Yaw rate > 1°/s (See 3.3.1.1.2)	Brake failure & drive train loaded
6.6	Yaw Error Large and Wind Direction Sensor Mismatch	Mismatch > 10° (See 3.3.1.1.2)	Loose mounting plus high winds
6.7	Rotor Brake Status Fault	Status ≠ Cmd (Rotating)	Solenoid Failure

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Table 9-8

First Level Fault Condition (NSD → SBI)

- Operator Command
- Blade temperature 30 minute time out
- Ice detected
- Generator winding temperature > 275°F
- Stator tie breaker trip without lockout relay trip
- Emergency or backup emergency shutdown flick verification check failure in start-up
- Three consecutive start-up attempts without achieving the power generate mode

Standby/Enable

In standby/enable, the system is permitted to operate, no faults have been detected, and the controller is awaiting acceptable wind conditions.

9.2.4.4 Data Archiving

The base data log sample comprises 50 words of analog and packed discrete functions. A 30-second running data log, at one sample per second, is maintained during operation. When a forced shutdown occurs, the 30-second log of data before shutdown is preserved. The data representing post-shutdown performance is preserved in two segments, 30 samples at one sample per second and, 30 samples at one sample per 5 seconds. The data is examined or dumped with commands in the manual state.

9.2.4.5 Power Generate

Throughout power generate the aileron control is proportional plus integral with speed error. The control angle command is defined as:

$$\delta = \delta_{-1} + G_1 \Delta E_n + G_2 E_n \Delta t$$

Where δ_{-1} is the position in the last cycle

E_n = $N_R - N_{R\ ref}$ (rpm)

ΔE_n = $N_R - N_{R-1}$ (rpm)

Δt = controller cycle time, 0.1 second baseline

G_1 = proportional gain, 30°/rpm, with a ±0.07 rpm deadband

G_2 = integral gain, 5°/sec/rpm, with an anti-windup clamp

The rotor speed reference $N_{R\ ref}$ is 13.8 for low speed or 16.8 for high speed. The generator speed reference $N_{G\ ref}$, in the rotor reference frame, is initially set equal to rotor speed, then is proportional to speed error with a gain of 1.67 times rated torque/rpm. This gain and a torque clamp at 1.1 times rated torque are provided with hardware external to the controller.

Low wind shutdown is defined as the output power less than or equal to zero for 5 min.

High wind shutdown is defined by the aileron angle,

$\delta_{av} \geq (33° - 12 * P_{sp})$ where P_{sp} is power set point

The transition from low speed, $N_{R\ ref}$ = 13.8 rpm to high speed, $N_{R\ ref}$ = 16.8 rpm, is initiated when the 5-minute average of the power output is greater than 4500 kW. The wind rotor is more efficient at the higher speed above this power level.

The transition from high speed to low speed is initiated when the 5-minute average of the power output is less than 3000 kW. The hysteresis between 3000 kW and 4500 kW avoids frequent shifting.

The transition between high and low speed is implemented by simultaneously changing the speed references, $N_{R\ ref}$ and $N_{G\ ref}$, at a rate of 1 rpm/min referred to rotor speed. Figure 9-14 is a logic diagram of the power generate mode.

9.2.4.6 Manual

This is the state in which the on-site operator controls individual functions of the wind turbine. Manual mode is entered from lockout mode. The mode is initiated by the keyswitch on the system display panel. The manual commands are listed in Table 9-9.

9.2.4.7 Communications

Communications between the site or remote operator's terminal and the controller are bidirectional. Only one of the terminals can communicate with the controller at a time. The terminal that has control must relinquish the control before the other terminal can obtain control. For security, each terminal has a password. The correct password must be entered before commands will be accepted.

The controller will continue to operate if the communication link is lost. The communication link is necessary to bring the controller out of the standby/inhibit mode into the standby/enable mode. In other modes it provides added capabilities or information. Table 9-10 is a command list for the

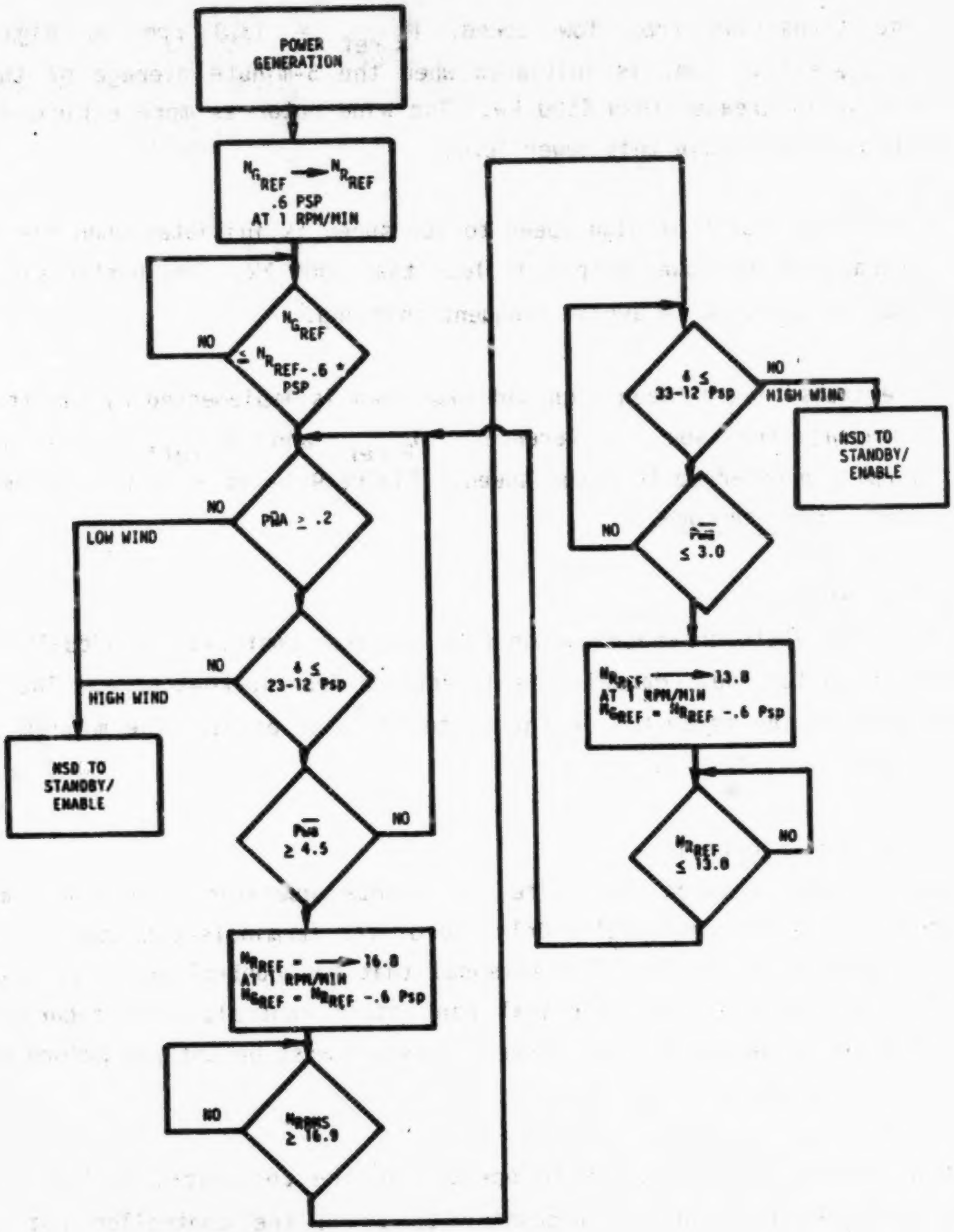
POWER GENERATION
NGREF → NRREF .6 PSP AT 1 RPM/MIN
NGREF ≤ NRREF-.6 * PSP
NO
PWA ≥ .2
NO
LOW WIND
δ ≤ 23-12 Psp
NO
HIGH WIND
HSD TO STANDBY/ ENABLE
PWA ≥ 4.5
NO
NRREF = → 16.8 AT 1 RPM/MIN NGREF = NRREF -.6 Psp
NRRMS ≥ 16.9
NO
δ ≤ 33-12 Psp
NO
HIGH WIND
HSD TO STANDBY/ ENABLE
PWA ≤ 3.0
NO
NRREF → 13.8 AT 1 RPM/MIN NGREF = NRREF -.6 Psp
NRREF ≤ 13.8
NO

Figure 9-14 Power Generate

Table 9-9 Manual Control Command List

FUNCTION		COMMAND
ROTOR HYDRAULIC PUMP	- ON	A1
	- OFF	A0
YAW HYDRAULIC PUMP	- ON	B1
	- OFF	B0
GEARBOX AND GENERATOR LUBE PUMPS	- ON	C1
	- OFF	C0
SHAFT BRAKE	- ON	D1
	- OFF	D0
TEETER BRAKE HIGH FORCE	- ON	E1
	- OFF	E0
YAW BRAKES	- ON	F1
	- OFF	F0
FEATHER VALVE A1	- ENERGIZE	G1
	- DE-ENERGIZE	G0
FEATHER VALVE A2	- ENERGIZE	H1
	- DE-ENERGIZE	H0
AILERON SET 1 ANGLE	- XX DEG	IXX
AILERON SET 2 ANGLE	- XX DEG	JXX
TURNING GEAR	- ON	K1
	- OFF	K0
EMERGENCY SHUTDOWN	- ENABLE	L1
YAW DRIVE	- XX SEC CW	M + XX
	- XX SEC CCW	M - XX
DUMP DATA ARCHIVE	- XX LINE INTERVAL	NXX
	- X LINES START AT LINE YYY	OXYYY

Table 9-10 Operator's Terminal Command List

FUNCTION	COMMAND
STANDBY ENABLE	01
SPEED SET POINT (XX.X RPM)	1 XXX
POWER SET POINT (XX.X MW)	2 XXX
NORMAL SHUTDOWN	31
EMERGENCY SHUTDOWN	41
REQUEST TERMINAL CONTROL	51
ENABLE TERMINAL CONTROL	61
ZERO CUMULATIVE ENERGY	71
TIME SET (XXHR:YYMIN)	8XXYY
MONTH/DATE SET (XXMO:YYDATE)	9XXYY
PRINT ONE LINE OF DATA	:1 (COLON 1)
CONNECT TERMINAL	;1
DISCONNECT TERMINAL	;0

operator's terminals. The print out, sample shown in Figure 9-15, includes the following data:

- month, day, hour, minute, and second
- terminal control
- cumulative energy produced yesterday
- cumulative energy produced since specified date
- speed set points
- power set points
- var set point
- alarm number
- wind speed
- power
- energy
- Mode (LO, SBI, SBE, SU, RMP, PWR, NSD)

Communications between the controller and the controls data system support checkout and initial operation. The output of the controller consists of the packed discrete I/O, analog I/O, alarms, and RAM values. The controls data system can request the controller to read values out of RAM and change th value in a RAM location.

9.2.4.8 Start-up

The conditions for start-up are:

- The system must be in the standby/enable mode
- $14 \leq$ Wind speed (5 minute average) ≤ 55
- Yaw error $\leq 7°$

The start-up sequence logic is shown in Figure 9-16. The flick tests confirm that the emergency shutdown, backup emergency shutdown, and aileron control subsystems are functioning before every rotation.

9.2.4.9 Ramp/Sync

Ramp/sync is activated after start-up, when the wind speed is in the operating range. The following describes the ramp/sync sequence. Logic diagrams for ramp/sync are shown in Figures 9-17, 9-18, and 9-19.

- use generator in motoring mode to accelerate rotor to 3.7 rpm.
- ramp rotor speed from 3.7 to 13.8 rpm using aerodynamic torque control.
- synchronize the generator by enabling the converter control described in section 9.1.5. Enter power generate mode when synchronization is completed.

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```
  0.00      0.00.00        MOD 5A SUMMARY DATA UNIT SN 001

                MWH PRODUCED                                      SET POINTS
    CONTROL  YESTER   CUMM       FROM         TA%         MW      RPM      PAGE
 HEADING
    SITE         .0    .00       0.00          .0        7.3     17.9

     TIME        ALRM     MPH        MW          MWH        MODE

    0.00.12      +10
    0.00.12        0       .1      -.19          .0          LO
    0.00.18      +11                                                    POWER UP
    0.00.18      +80                                                       ALM 10 - TEETER ANGLE
    0.00.24      +25                                                       ALM 11 - TEETER ACCUM
    0.00.24      -10                                                                PRESS LD
    0.00.30      -11                                                             80 - LOCK OUT RELAY
    0.00.30      -80                                                             85 - YAW BRAKE/GRIPPER
    0.00.48        0       .1      -.19          .0         SBI         KEYSWITCH RESET
[redacted]                                                              PASSWORD - ENABLE TERMINAL
                                                                        CMD INPUT
81427                            0.01.48                                SET TIME
90242                           14.27.06                                SET DATE
01                          14.27.18                                    CMD SBE
   14.27.24        0       .1      -.19          .0         SBE
   14.33.24        0     15.0      -.14          .0          SU
   14.35.30        0     15.0      1.14          .0         RMP         AUTO SEQUENCE
   14.40.30        0     15.0      1.14          .0         PWR
:1                              14.41.30                                REQUEST PRINTOUT
   14.41.36        0     15.0      1.30          .0         PWR
31                              14.41.48                                CMD NORMAL SHUTDOWN
   14.41.48      +51                                                    ALM 51  CMD NSD
   14.41.54        0     15.0      1.70          .0         NSD
   14.43.18        0     15.0      -.17          .0         SBI
   14.43.24      -51
01                              14.43.42
   14.43.48        0     25.0      -.19          .0         SBE
   14.47.42        0     25.0      -.19          .0          SU
   14.49.48        0     25.0      -.17          .0         RMP
   14.54.18        0     25.0      1.41          .0         PWR
   14.55.30        0     25.0      5.75          .0         NSD
   14.55.36      +55                                                    LUB TEMP
   14.55.36      -55
   14.57.00        0     25.0      -.17          .1         SBI
01                              14.57.30
   14.57.30        0     39.8      -.19          .1         SBE
   15.01.30        0     39.8      -.19          .1          SU
   15.03.36        0     39.8      -.18          .1         RMP
   15.07.54        0     39.8      1.18          .1         PWR
   15.12.36        0     39.8      7.26          .6         NSD
   15.12.42      +61                                                    INTRUSION ALM
   15.12.48      -61
   15.14.18        0     39.8      -.15          .6          LO
   15.29.18        0     39.8      -.23          .6          LO
   15.44.18        0     39.8      -.21          .5          LO
   15.59.18        0     39.8      -.19          .5          LO
   16.03.54        0     39.8      -.23          .4         SBI
01                              16.04.06
   16.04.06        0     15.0      -.23          .4         SBE
   16.08.06        0     15.0      -.19          .4          SU


  4.24   16.08.12       MOD 5A SUMMARY DATA UNIT SN 001

                MWH PRODUCED                                   SET POINTS
 CONTROL  YESTER    CUMM       FROM         TA%         MW      RPM
 SITE         .0     .00       0.00        51.0        7.3     17.9

  TIME        ALRM      MPH        MW          MWH        MODE

  16.09.48       0     15.0      -.15          .4          SU
  16.10.06       0     15.0      -.17          .4         RMP
  16.15.06       0     15.0      1.24          .4         PWR
  16.25.54       0     54.8      7.20         1.5         NSD
  16.26.00     +79                                                      GENERATOR VIBRATION
  16.26.00     -79
  15.27.30       0     54.8      -.15         1.5          LO
  15.42.30       0     54.8      -.19         1.5          LO
```

Figure 9-15 Sample Terminal Output

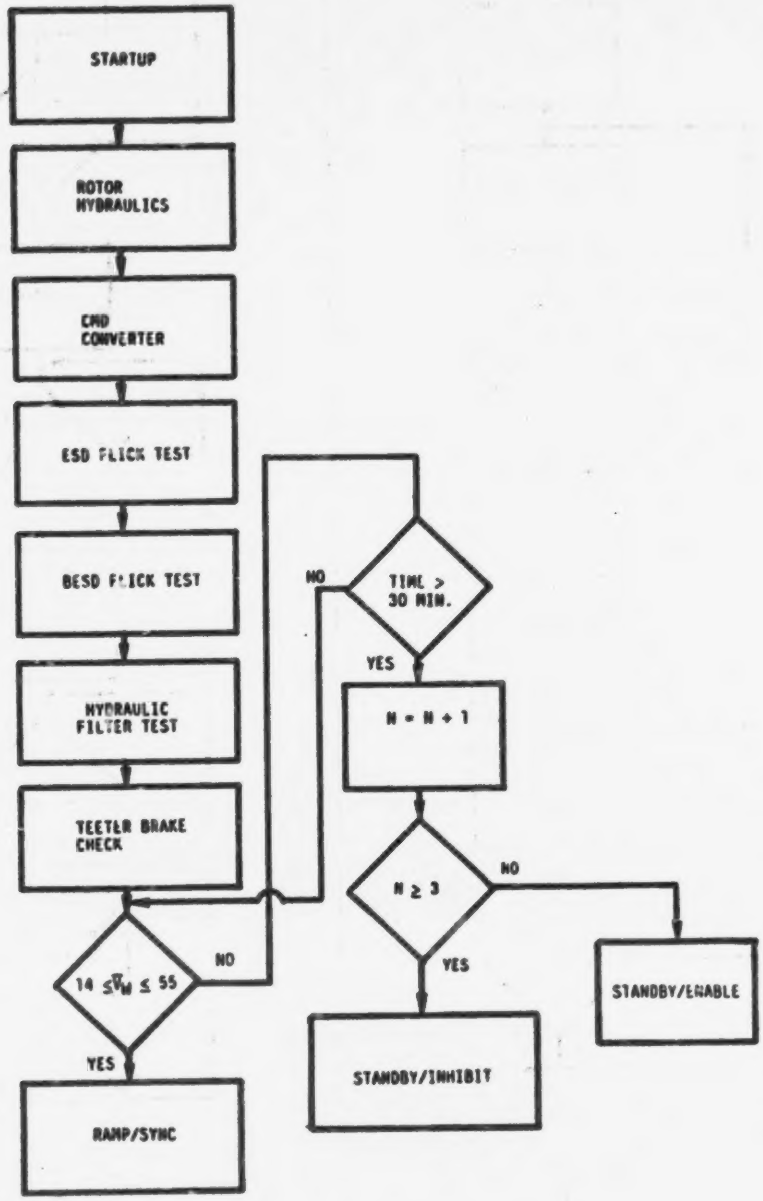

STARTUP
ROTOR HYDRAULICS
CMD CONVERTER
ESD FLICK TEST
BESD FLICK TEST
HYDRAULIC FILTER TEST
TEETER BRAKE CHECK
$14 \leq \bar{V}_M \leq 55$
NO
YES
RAMP/SYNC
TIME > 30 MIN.
NO
YES
N = N + 1
N ≥ 3
NO
YES
STANDBY/INHIBIT
STANDBY/ENABLE

Figure 9-16 Start-up

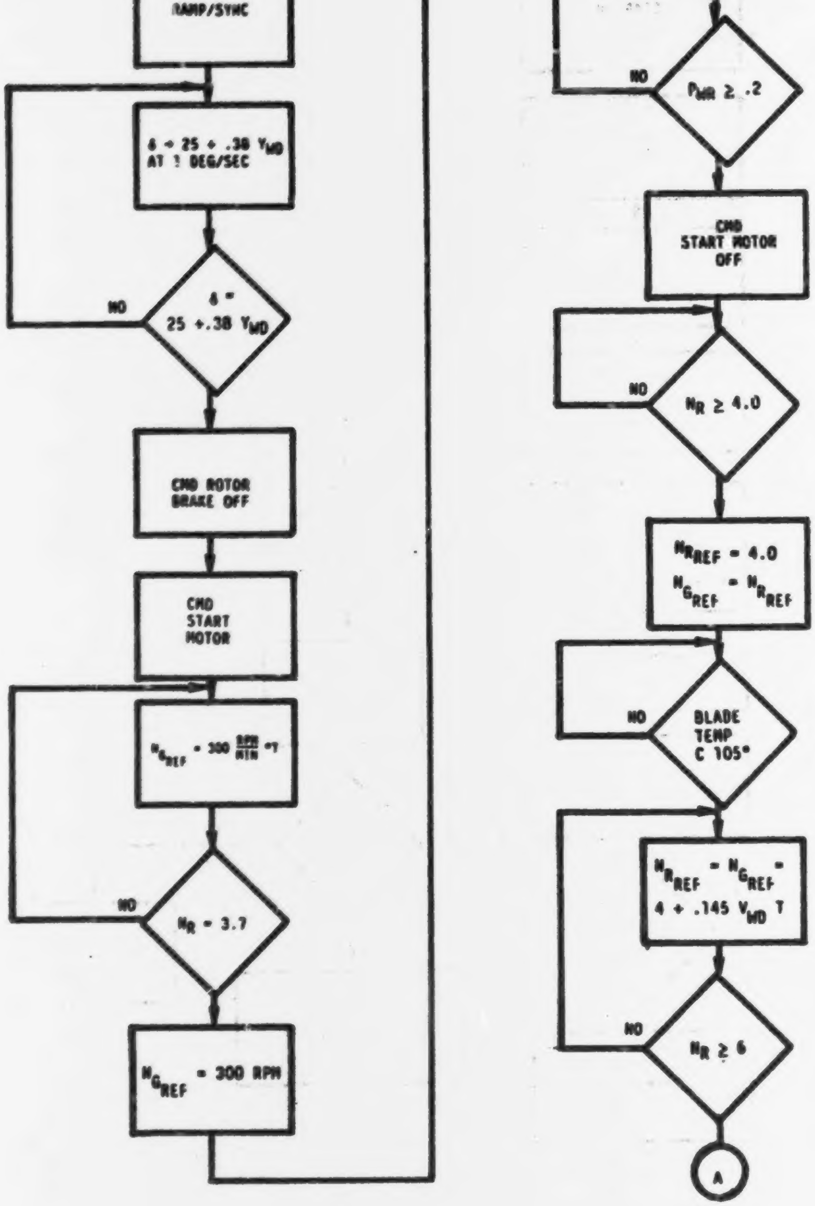

RAMP/SYNC
δ → 25 + .38 Y_WD AT 1 DEG/SEC
NO
δ = 25 +.38 Y_WD
CMD ROTOR BRAKE OFF
CMD START MOTOR
N_G_REF = 300 RPM/MIN •T
NO
N_R = 3.7
N_G_REF = 300 RPM
N_G_REF = 3.7 + 1.8T
NO
P_WR ≥ .2
CMD START MOTOR OFF
NO
N_R ≥ 4.0
N_R_REF = 4.0
N_G_REF = N_R_REF
NO
BLADE TEMP C 105°
N_R_REF = N_G_REF = 4 + .145 V_WD T
NO
N_R ≥ 6
A

Figure 9-17 Ramp/Sync

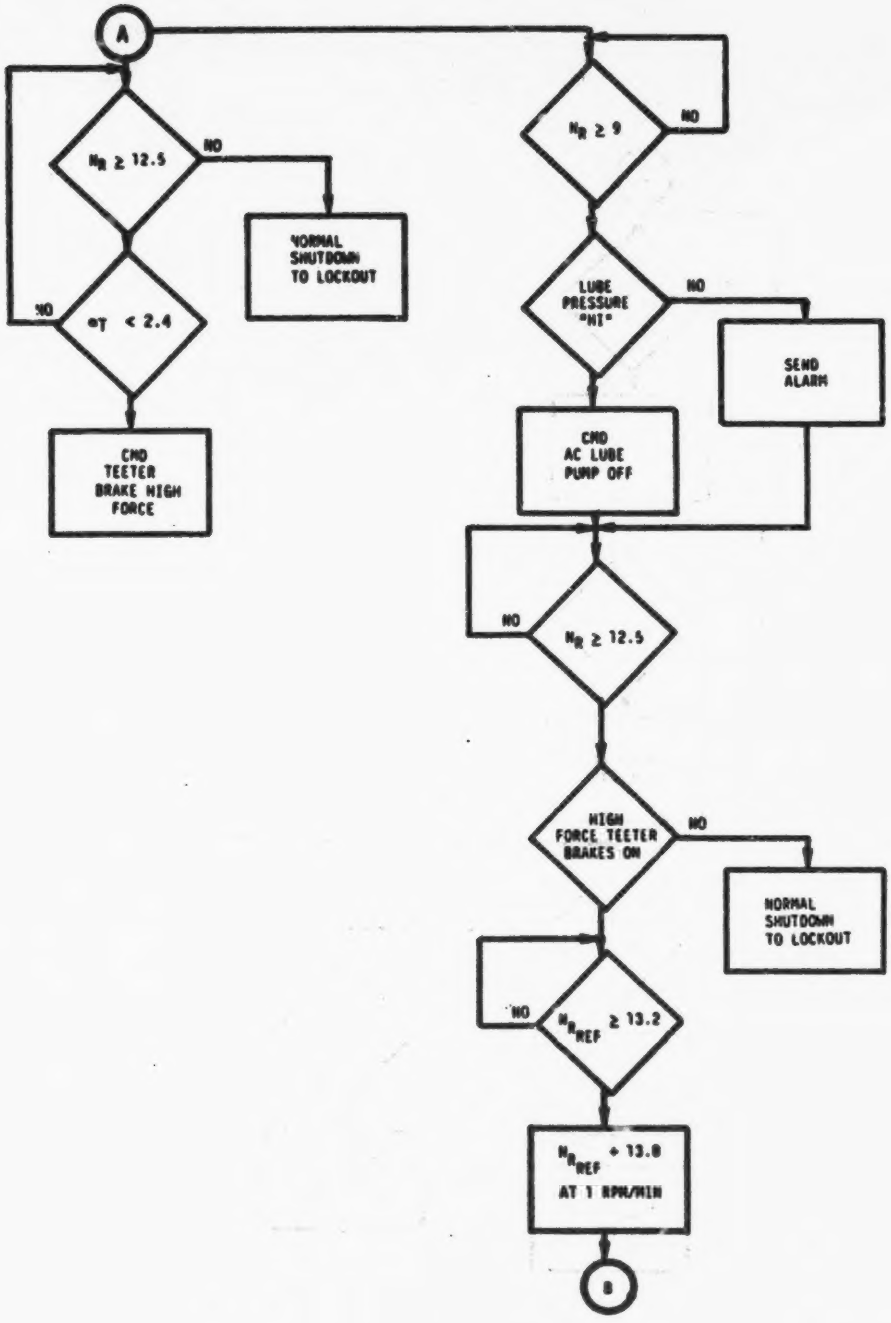

A
$N_R \geq 12.5$
NO
NORMAL SHUTDOWN TO LOCKOUT
NO
$\theta_T < 2.4$
CMD TEETER BRAKE HIGH FORCE
$N_R \geq 9$
NO
LUBE PRESSURE "HI"
NO
SEND ALARM
CMD AC LUBE PUMP OFF
NO
$N_R \geq 12.5$
HIGH FORCE TEETER BRAKES ON
NO
NORMAL SHUTDOWN TO LOCKOUT
NO
$N_{R_{REF}} \geq 13.2$
$N_{R_{REF}} \leftarrow 13.8$
AT 1 RPM/MIN
B

Figure 9-18 Ramp/Sync (Cont'd.)

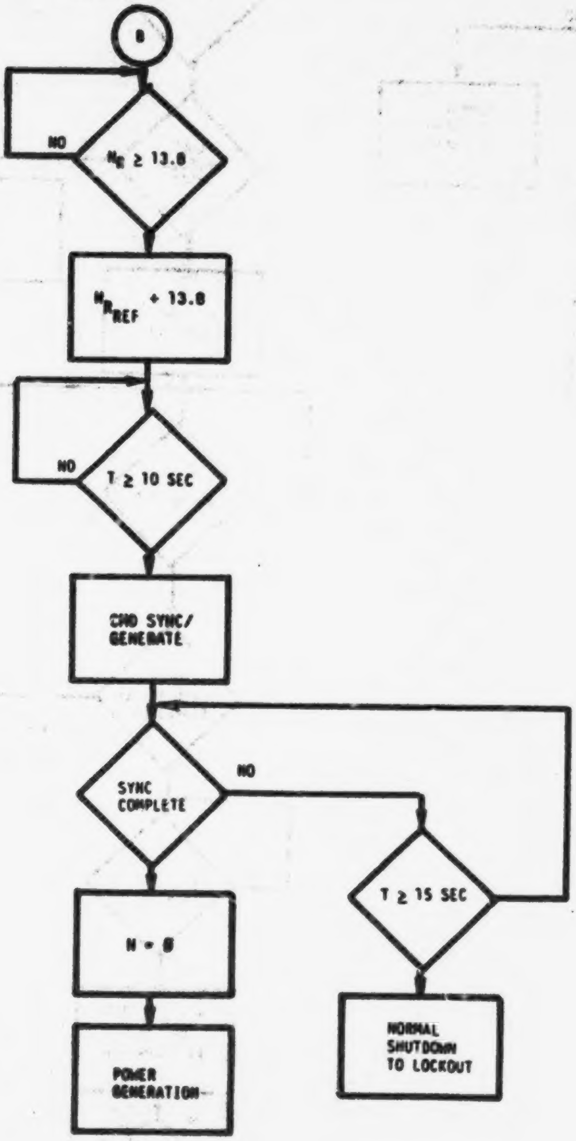

B
NO
$N_R \geq 13.8$
$N_{R_{REF}} \leftarrow 13.8$
NO
$T \geq 10$ SEC
CMD SYNC/
GENERATE
SYNC
COMPLETE
NO
$T \geq 15$ SEC
N = 0
POWER
GENERATION
NORMAL
SHUTDOWN
TO LOCKOUT

Figure 9-19 Ramp/Sync (Cont'd)

9.2.4.10 Yaw

The yaw module is activated during the automatic sequence when the wind speed is greater than 12 mph. This module commands the yaw drive to rotate the nacelle, based on the yaw error. The yaw error is the relative difference in the wind direction relative to the nacelle position. The yaw correction is executed when the yaw error is greater than 7° and stops when the yaw error is less than 3.5°. When the yaw drive is not active, both the yaw motive brakes and the yaw holding brakes will be "ON". During operation, the brakes and gripper are operated in an "apply-before-release" sequence. The controller operates the yaw drive brakes and actuators as shown in Figure 9-20.

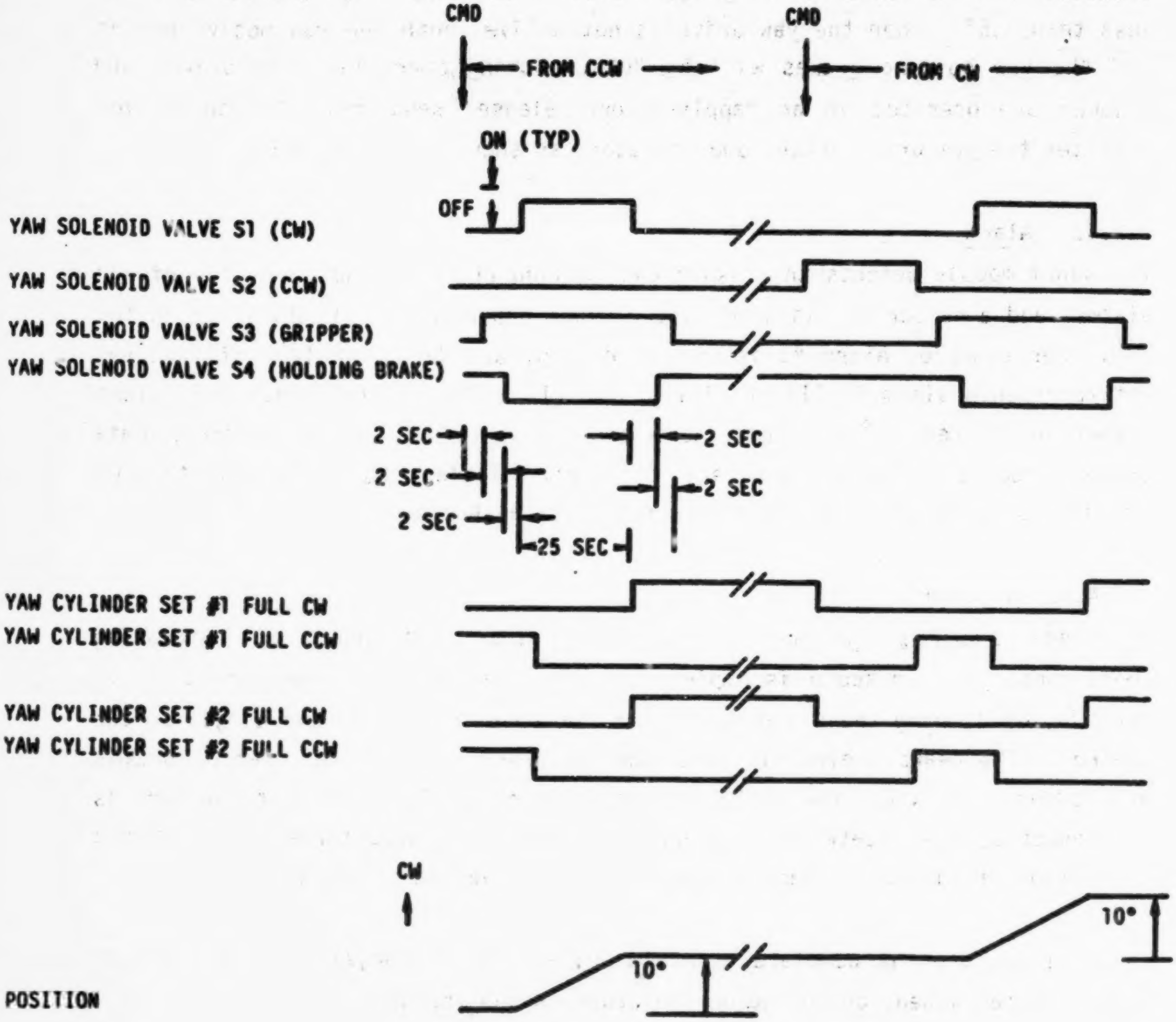
9.2.4.11 Alarm

The alarm module detects the rising and falling (turn on and turn off) of all alarms, and a number is assigned to the alarm depending on its location in the RAM. For example, Alarm #1 is 001 if rising, and 129 (1 + 128) if falling. The fourteenth alarm is 014 if rising, 142 (14 + 128) if falling. This alarm number is stored in an alarm table and is sent out to the controls data system, remote terminal and site terminal. Table 9-11 lists the trigger conditions for alarm. An alarm does not start a shutdown.

9.2.4.12 Shutdown

A normal shutdown can be initiated any time and under all operating conditions. The shutdown is implemented by lowering the system speed at 10 rpm/min, by ramping the speed references for aileron control and airgap torque control. The gearbox electric lube pump is turned on at 9 rpm. Rotor brakes are turned on when the aileron controls reach 70°. The converter is disconnected, full teeter brakes applied, and lube pumps turned off, at the completion of shutdown. Figure 9-21 is a logic diagram of shutdown.

When the shutdown is complete, the standby/enable, standby/inhibit or lockout mode is established, depending on the cause of the shutdown.



CMD
FROM CCW
CMD
FROM CW
ON (TYP)
OFF
YAW SOLENOID VALVE S1 (CW)
YAW SOLENOID VALVE S2 (CCW)
YAW SOLENOID VALVE S3 (GRIPPER)
YAW SOLENOID VALVE S4 (HOLDING BRAKE)
2 SEC
2 SEC
2 SEC
25 SEC
2 SEC
2 SEC
YAW CYLINDER SET #1 FULL CW
YAW CYLINDER SET #1 FULL CCW
YAW CYLINDER SET #2 FULL CW
YAW CYLINDER SET #2 FULL CCW
CW
10°
10°
POSITION

Figure 9-20 Yaw Drive Sequence

Table 9-11 Alarms

	Condition	Trigger Condition	Expected Cause
I.	GENERAL CS		
A1.1	Aircraft Warning Strobes Inop.	Local Sensor	Strobe Failure
A1.2	Fire Equipment Activated	Local Sensor	Fire Conditions
A1.3	Control Enclosure Cabinet Temp "HI"	$T > 104°F$	Heat Exchanger Failure
A1.4	Wind Speed Sensor Mismatch	$\Delta > 5$ mph (See 3.3.1.1.2)	Sensor Failure
A1.5	C.E.C. Temp. Out-of-Range	$T > 50°C$ or $T < 0°C$	Heat/Cooling Equip. Failure
II.	AILERON ACTUATION & TEETER BRAKE		
A2.1	Rotor Hyd. Oil Filter ΔP "HI"	$\Delta P > 40$ psi	Filter Clog/Cold oil
A2.2	Rotor Hyd. Main Accum. Press. "LO"	$P < 2000$ psi	Leak/pump failure
A2.3	Rotor Hyd. Res. Oil Level "LO"	$P \leq 5$ psi = low oil	Leak/bad sensor
A2.4	Rotor Hyd. Oil Temp. "HI"	$T > 145°F$	Heater failure
A2.5	Rotor Hyd. Pump Discharge Press. "LO"	$P < 2000$ psi	Leak/pump failure
A2.6	Teeter Angle "HI"	$\|\alpha_T\|$ 4° (analog signal)	Blade unbalance/Loose sensor
A2.7	Teeter Accum. Press. "LO"	$P < 2000$ psi	Leak/pump failure
III.	ROTOR		
A3.1	Blade Temperature "HI"	$T > 105°F$ (See 3.2.2.1.4)	Temp. Soak @ Standstill
IV.	GEARBOX LUBE		
A4.1	One-of-three Supply Press. "LO"	$P < 60$ psi	Leak/pump failure
A4.2	Shaft Driven Pump Press. "LO"	$P < 60$ psi	Leak/pump failure
A4.3	Lube Filter ΔP "HI"	$\Delta P > 10$ psi	Filter clog/cold oil
A4.4	Lube Supply Temp. "HI"	$T > 120°F$	Cooler failure
A4.5	Lube Supply Temp. "HI-HI"	$T > 135°F$	Cooler failure
A4.6	Lube Sump Temp. "HI"	$T > 140°F$	Heater failure
A4.7	Lube Sump Temp. "LO"	$T < 60°F$	Heater failure/Initial Start
A4.8	Lube Sump Oil Level "LO"	Level < 100 gal.	Leak/bad sensor
V.	GENERATOR/CONVERTER		
A5.1	Generator Lube Level "LO"	Level < 5 gal.	Leak/bad sensor
A5.2	Generator Lube Filter ΔP "HI"	$P > 10$ psi	Filter clog/cold oil
VI.	YAW ACTUATION & ROTOR BRAKES		
A6.1	Yaw Holding Brk. Accum. Press. "LO"	$P < 1800$ psi	Leak/pump failure
A6.2	Yaw Main Accum. Press. "LO"	$P < 1800$ psi	Leak/pump failure
A6.3	Hyd. Filter ΔP "HI"	$P > 80$ psi	Filter clog/cold oil
A6.4	Oil Temperature "HI"	$T > 140°F$	Heater failure
A6.5	Oil Level "LO"	Level < 10 gal.	Yaw hyd. leak
A6.6	Yaw Motive Brk. Status Fault	Status ≠ Cmd	Leak/pump failure
A6.7	Wind Direction Sensor Mismatch	Angle > 10° (See 3.3.1.1.2)	Loose Mounting
A6.8	Rotor Brake Status Fault	Status ≠ Cmd (non-rotating)	Solenoid Failure
A6.9	Rotor Brake Accum. Press. "LO"	$P < 1800$ psi	Leak/pump failure

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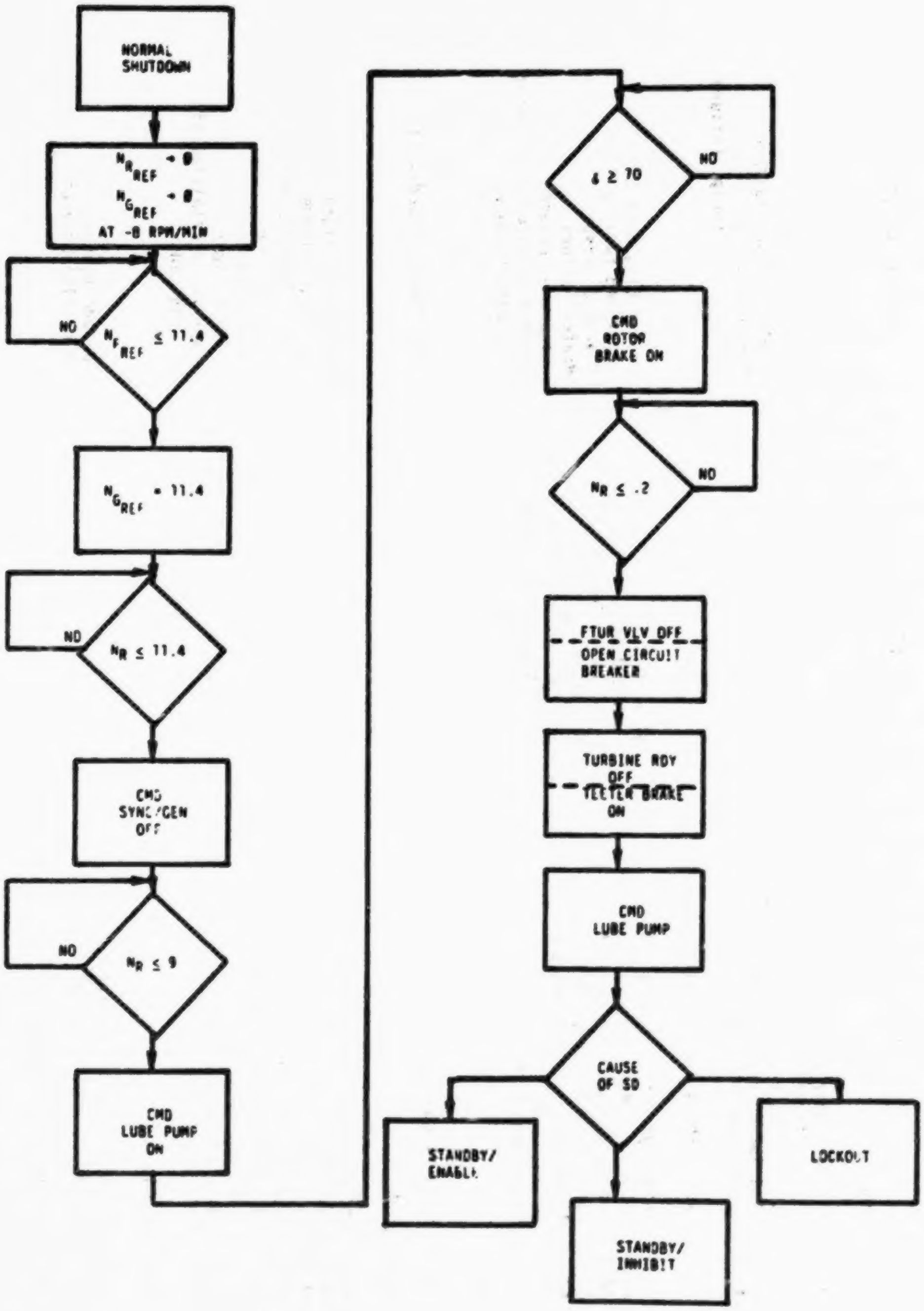
NORMAL SHUTDOWN
$N_{R_{REF}} \to 0$
$N_{G_{REF}} \to 0$
AT -8 RPM/MIN
NO
$N_{F_{REF}} \leq 11.4$
$N_{G_{REF}} = 11.4$
NO
$N_R \leq 11.4$
CMD SYNC/GEN OFF
NO
$N_R \leq 9$
CMD LUBE PUMP ON
$\beta \geq 70$
NO
CMD ROTOR BRAKE ON
$N_R \leq .2$
NO
FTUR VLV OFF
OPEN CIRCUIT BREAKER
TURBINE RDY OFF
TEETER BRAKE ON
CMD LUBE PUMP
CAUSE OF SD
STANDBY/ ENABLE
LOCKOUT
STANDBY/ INHIBIT

Figure 9-21 Normal Shutdown

9.2.4.13 Output Signal Manager

The output signal manager module issues the output commands generated during the executive cycle by transferring information from RAM to the output hardware. This is provided by the ECL executive.

9.2.4.14 Memory Test

The planned memory test operates in the background during the slack period at the end of each executive cycle. The test sums incrementally through the test cycle to test the CPU, PROM, & RAM. The CPU test checks the instruction set. The PROM test compares the sum of values in 2K memory increments with a known checksum value.

The RAM test follows the following sequence:

- disable interrupts
- save current contents
- write all 0's and verify
- write all 1's and verify
- bit ripple and verify
- restore current contents
- enable interrupts

The user software was planned to check the error detecting functions of the watch dog timer and parity checker during the start-up mode.

Memory test software had not been implemented when design activity was suspended.

9.2.5 VENDOR SOFTWARE

Three vendor supplied software packages are used. They are:

- Real time clock and calendar
  SL709-6015-M RTCCND, RTG clock/calendar.
- Print and key-in communication
  SL709-6034-M PRTKYND, Type D Print/Keyin
- General data communication
  SL 709-6037-01 CP7COMD, CP717 Comm Pkg

9.2.5.1 Real Time Clock and Calendar

The real time clock and calendar program counts 0.1 second pulses to determine the month, day, hour, minute, and second.

The date is updated at midnight. The month is updated at 28, 30, or 31 days. There is no provision for updating the year. In a leap year, 2 March must be reset to 1 March manually.

9.2.5.2 Print and Keyin Communication

The EPTAK executive (ECL) software can control communications between the controller and one print/keyin device. A supplementary subroutine enables the software to control communications between the controller and up to 15 print/keyin devices. Both the site and remote operator terminals are print/keyin devices and provision for communication with two devices was a minimum MOD-5A requirement.

The print/key-in interface protocol is TTY/EIA RS232C with 20mA current loop.

Standard ASCII Code is used at BAUD rates between 110 and 9600. Parity can be odd, even, or none. Stops bits can be 1, 1 1/2, or 2. Bits per character can be 5, 6, 7 or 8. The MOD-5 application settings are 300 BAUD, 8 bits/character, 1 stop bit, and no parity. The information transmitted is alpha-numeric and does not require processing at the terminals.

9.2.5.3 General Data Communications

The general data communications software package enables the controller to communicate with the controls data system through an RS 232C interface.

The format of the 8 bit data message word used with this software is 0011XXXX where XXXX is 4 bits of data. An 8 bit data word is transmitted in 2 message words with the 4 most significant data bits in the first message word and the 4 least significant data bits in the second message word. The data word $A_7A_6A_5A_4A_3A_2A_1A_0$ is thus transmitted by the data message words $0011A_7A_6A_5A_4$ and $0011A_3A_2A_1A_0$.

The 50 word data set, composed of MOD-5A operating data and alarms, is transmitted to the controls data system by a 100 word message. The data set is transmitted once per second at 1200 BAUD. The controls data system processes the data message words and reconstructs the data words.

9.3 CONTROL INSTRUMENTATION

9.3.1 SENSORS

The requirements for sensors whose signals are inputs to the control system are:

- Discrete inputs interrupt 120 Vac, 60 Hz, 6 mA power when an event occurs, by switch closures either directly from sensors or as a result of signal conditioning.
- Analog signals are conditioned to have a range of 4 to 20 mA, or the sensor is purchased with that range.
- Each sensor is required to operate in the following environment: temperatures of -30°C to +40°C, vibration of ±.25 g's on any axis, relative humidity of 5% to 90%. Some sensors are subject to other requirements, such as resistance to hydraulic or lubricating oils.

A complete list of the sensors for the control system, listing the value to be measured, type of sensor, range, etc. is shown in Table 9-12. A list of commands is shown in Table 9-13.

Whenever possible, sensors were supplied as part of a subsystem. The following items were not purchased as part of a subsystem. Purchased signal conditioning is described in this section and custom designed signal conditioning circuits are described in section 9-13.

Wind Speed and Direction Sensor

The Aerovane Transmitter measures both the speed and direction of the wind. It was designed for the U.S. Navy, and is a durable and reliable instrument for measuring winds up to 200 mph in many environments.

The speed transducer is a rugged dc magneto. Its output is linear at 106 mV per mph. The three-blade, molded propeller-type sensor has a 12 in. diameter and is coupled to the dc magneto. Its maximum threshold is 2.5 mph and its distance constant is 15 ft. The wind direction is measured by a streamlined vane with a damping ratio of approximately 0.28 and a distance constant of 34 ft. A Type IHG synchro, which runs on 115 V, 60 Hz, transmits the wind direction to a synchro to dc converter.

Two of these sensors are mounted on masts attached to the nacelle. One unit is used for control and the other is used for validity.

Table 9-12 Control Sensors

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	RANGE OR TRIP POINT	ACC'Y.	OUTPUT A	OUTPUT B	COMMENTS
10	ICE DETECTION BL. 1	RESONANT PROBE	S1.1	0.2 IN.	±0.05 IN.		B	
20	ICE DETECTION BL. 2	RESONANT PROBE	S1.2	0.2 IN.	±0.05 IN.		B	
30	HI TEMP BL. 1	RTD	S1.3	109°F	±2%		B	(1)
40	HI TEMP BL. 2	RTD	S1.4	109°F	±2%		B	(1)
50	HI STRAIN BL.1	STRAIN GAGE	S1.5	TBD			B	(1)
60	HI STRAIN BL.2	STRAIN GAGE	S1.6	TBD			B	(1)
70	AILERON POSITION 1-1	LVDT	S2.21	0 TO 10 IN.	±.03 IN	A		
80	AILERON POSITION 1-2	↓	S2.22	↓	↓	A		
90	AILERON POSITION 1-3	↓	S2.23	↓	↓	A		
100	AILERON POSITION 1-4	↓	S2.24	↓	↓	A		
110	AILERON POSITION 2-1	↓	S2.25	↓	↓	A		
120	AILERON POSITION 2-2	↓	S2.26	↓	↓	A		
130	AILERON POSITION 2-3	↓	S2.27	↓	↓	A		
140	AILERON POSITION 2-4	LVDT	S2.28	0 TO 10 IN.	±.03 IN	A		
150	RHP HYD. RESV. LEVEL	PRESSURE SWITCH	S2.3	5 PSI	±2%		B	INDICATES LOW OIL LEVEL
160	RHP HYD. OIL FILTER	Δ PRESSURE SWITCH	S2.4	40 PSI	±5%		B	
170	RHP HYD. OIL TEMP.	TEMPERATURE SWITCH	S2.5	145°F	±1%		B	
180	RHP ACCUM PRESS.	PRESSURE SWITCH	S2.14	2000 PSI	±1%		B	
190	RHP PUMP PRESS.	PRESSURE SWITCH	S2.6	2000 PSI	±1%		B	
200	AILERON LATCHES	LIMIT SWITCHES	S2.30	-	-		B	8 SWS IN SERIES
210	AILERON PRESSURES	PRESSURE SWITCHES	S2.31	2000 PSI	±1%		B	8 SWS IN SERIES
220	TEETER BRAKE ACCUM'S. PRESS	PRESSURE SWITCHES	S2.7	1500 & 2750 PSI	±1%		B	2 SWS IN PARALLEL
230								
240	TEETER BRAKE H. F. SOLENOID 'ON'	VOLTAGE SENSE	S2.12	-	-		B	
250	TEETER ANGLE	SYNCHRO	S2.18	±10°	±2%	A		

NOTE: (1) Signal Conditioning and Limit Alarm Module required

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Table 9-12 Control Sensors (continued)

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	RANGE OR TRIP POINT	ACC'Y.	OUTPUT A	OUTPUT D	COMMENTS
260	TEETER ANGLE	LIMIT SWITCH	S2.19	±7.5°	±5%		D	LOCAL CONTROL
270	TEETER ANGLE	LIMIT SWITCH	S2.20	±5.0°	±5%		D	
280	TEETER HIGH FORCE BRAKE PRESS	PRESSURE SWITCH	S2.13	1500 PSI	±1%		D	
290	TEETER LOW FORCE BRAKE PRESS	PRESSURE SWITCH	S2.29	1500 PSI	±1%		D	
300	ROTOR VIBRATION	ACCELEROMETER	S3.3	0.1g	±2%		D	(1)
310	ROTOR SPEED	MAGNETIC	S3.4	0 → 30 RPM	±0.3%	A		
311	ROTOR SPEED	MAGNETIC	S3.15	11.5 → 17.5 RPM	±0.3%	A		
320	ROTOR POSITION	SYNCHRO	S3.10	0 TO 360°	±0.5%	A		
330	ROTOR POSITIONER DRIVE	LIMIT SWITCH	S3.11	-	-		D	
340	ROTOR BRAKE HI SPD SHAFT	PRESSURE SWITCH	S3.1	2000 PSI	±1%		D	
350	ROTOR BRAKE LO SPD SHAFT STG 1	PRESSURE SWITCH	S3.12	2000 PSI	±1%		D	
360	ROTOR BRAKE LO SPD SHAFT STG 2	PRESSURE SWITCH	S3.13	2000 PSI	±1%		D	
365	ROTOR BRAKE ACCUM PRESS	PRESSURE SWITCH	S3.14	1000 PSI	±1%		D	
370	LUBE RESV. LEV.	LEVEL SWITCH	S4.11	100 GAL	±5%		D	
380	LUBE RESV. HI TEMP.	TEMPERATURE SWITCH	S4.26	140°F	±2%		D	
390	LUBE RESV. LO TEMP.	TEMPERATURE SWITCH	S4.27	60°F	±2%		D	
400	LUBE SUPPLY TEMP. HI	TEMPERATURE SWITCH	S4.28	120°F	±1%		D	
410	LUBE SUPPLY TEMP. HI-HI	TEMPERATURE SWITCH	S4.29	135°F	±1%		D	
420	LUBE SUPPLY PRESS. "A"	PRESSURE SWITCH	S4.23	60 PSI	±1%		D	REDUNDANT SENSORS
430	LUBE SUPPLY PRESS. "B"	PRESSURE SWITCH	S4.24	60 PSI	±1%		D	
440	LUBE SUPPLY PRESS. "C"	PRESSURE SWITCH	S4.25	60 PSI	±1%		D	
450	LUBE SUPPLY FILT.	Δ PRESSURE SWITCH	S4.14	10 PSI	±5%		D	
460	SHAFT LUBE PUMP PRESS	PRESSURE SWITCH	S4.30	60 PSI	±1%		D	
470	GEN. RESV. LUBE LEVEL	LEVEL SWITCH	S5.6	5 GAL	±5%		D	
480	GEN. RESV. LUBE TEMP	TEMPERATURE SWITCH	S5.7	275°F	±1%		D	

NOTE: (1) Signal Conditioning and Limit Alarm Module required.

Table 9-12 Control Sensors (continued)

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	RANGE OR TRIP POINT	ACC'Y.	OUTPUT A	OUTPUT D	COMMENTS
490	GEN. LUBE PRESS.	PRESSURE SWITCH	S5.7	TBD			D	
500	GEN. BEARING TEMP	RTD	S5.8	250°F	±1%		D	(1)
510	GEN. WINDING TEMP.	RTD	S5.1	279°F	±1%		D	(1)
520	GEN. VIBRATION	VIBRATION SWITCH	S5.3	0.2IN/SEC	±2%		D	
530	GENERATOR SPEED	MAGNETIC	S5.9	-	-		D	PULSE TRAIN TO CYCLOCONVERTER
540	GENERATOR SPEED	MAGNETIC	S5.4	0 → 2000 RPM	±0.5%	A		
550	GENERATED POWER	PT'S, CT'S, TRANSDUCER	S5.5	-500 → 10,000 KW	±0.5%	A		
560	GENERATED REACTIVE POWER	PT'S, CT'S, TRANSDUCER	S5.10	-500 → 5,000KW	±0.5%	A		ALSO TO CONVERTER
570	YAW FILTER STATUS	Δ PRESSURE SWITCH	S6.8	80 PSI	±5%		D	
580	YAW HOLDING BRAKES STATUS	PRESSURE SWITCH	S6.9	2000 PSI	±1%		D	
590	YAW MOTIVE BRAKES STATUS	PRESSURE SWITCH	S6.10	2000 PSI	±1%		D	
600								
610	YAW HOLDING BRAKE ACCUM PRESS.	PRESSURE SWITCH	S6.2	1800 PSI	±1%		D	
620	YAW MAN ACCUM PRESS.	PRESSURE SWITCH	S6.13	1800 PSI	±1%		D	
630	YAW OIL LEVEL	LEVEL SWITCH	S6.3	10 GAL	±10%		D	
631	YAW MAIN ACCUM PRESS	PRESSURE SWITCH	S6.15	2700 PSI	±1%		D	LOCAL CONTROL
632	YAW HOLDING BRAKE ACCUM PRESS	PRESSURE SWITCH	S6.16	2700 PSI	±1%		D	
633	ROTOR BRAKE ACCUM PRESS	PRESSURE SWITCH	S6.17	2700 PSI	±1%		D	
635	YAW POSITION	SYNCHRO	S6.14	0 TO 360°	±1%	A		
640	YAW OIL TEMPERATURE	TEMPERATURE SWITCH	S6.12	170°F	±1%		D	
650	+Z CYLS CW POS'N	LIMIT SWITCH	S6.4	-	-		D	
660	+Z CYLS CCW POS'N	LIMIT SWITCH	S6.5	-	-		D	
670	-Z CYLS CW POS'N	LIMIT SWITCH	S6.6	-	-		D	
680	-Z CYLS CCW POS'N	LIMIT SWITCH	S6.7	-	-		D	
690	ESD SYSTEM READY	120 VAC PRESENCE	S7.4				D	SEE NOTE LINE 720

NOTE: (1) Signal Conditioning and Limit Alarm Module required.

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Table 9-12 Control Sensors (continued)

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	RANGE OR TRIP POINT	ACC'Y.	OUTPUT A	OUTPUT D	COMMENTS
700	NACELLE EMERGENCY STOP	MANUAL SWITCH	S7.8	-	-		D	
710	GROUND EMERGENCY STOP	MANUAL SWITCH	S7.9	-	-		D	
720	GENERATOR SPEED HI-HI	MAGNETIC	S7.10	1544 RPM	±1%		D	(1) PART OF THE AUTONOMOUS ESD
730	ROTOR SPEED HI-HI	MAGNETIC	S7.2	18.8 RPM	±1%		D	(1) ELECTRONICS
740	FEATHER VLV. A-1 CMD STATUS	RELAY	S7.13	-	-		D	
750	FEATHER VLV. A-2 CMD STATUS	RELAY	S7.14	-	-		D	
760	LOCKOUT RELAY STATUS	SWITCH	S8.1	-	-		D	
770	STATOR TIE STATUS	SWITCH	S8.3	-	-		D	
780	STATOR SHORT STATUS	SWITCH	S8.4	-	-		D	
790	CYCLOCONVERTER TIE STATUS	SWITCH	S8.5	-	-		D	
795	CONVERTER READY	SWITCH	S8.2	-	-		D	
800	UTILITY POWER PRESENCE	POWER MONITOR	S8.6	-	-		D	
810	INTRUSION ALARM	MAGNETIC SWITCHES	S9.1	-	-		D	SWITCHES IN SERIES
820	OIS/EIS STATUS	RELAY	S9.2	-	-		D	
830	CHARGER STATUS	RELAY	S9.3	-	-		D	P/O CHARGER
840	UPS BATTERY STATUS	RELAY	S9.10	-	-		D	P/O UPS
850	UPS INVERTER STATUS	RELAY	S9.11	-	-		D	
860	WIND SPEED #1	D-C MAGNETO	S9.4	0 → 150 MPH	±2 MPH	A		
870	YAW ERROR #1	SYNCHRO	S9.5	0 → 540°	±2°	A		
880	WIND SPEED #2	D-C MAGNETO	S9.6	0 → 150 MPH	±2 MPH	A		
890	YAW ERROR #2	SYNCHRO	S9.7	0 → 540°	±2°	A		
900	MANUAL	SWITCH	S9.17	-	-		D	KEY OPERATED SWITCH
910	LOCKOUT	SWITCH	S9.18	-	-		D	
920	AUTOMATIC	SWITCH	S9.19	-	-		D	
930	RESET	SWITCH	S9.20	-	-		D	

NOTE: (1) Signal Conditioning and Limit Alarm Module required

Table 9-12 Control Sensors (continued)

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	RANGE OR TRIP POINT	ACC'Y.	OUTPUT A	OUTPUT D	COMMENTS
940	NACELLE FIRE ALARM	SWITCH	S9.12	-	-		D	PART OF NACELLE FIRE EQUIPMENT
950	C.E.C. AIR FLOW	SWITCH	S9.13	250 FPM	±100 FPM		D	2 SWS IN SERIES
960	C.E.C. TEMP. HI	TEMPERATURE SWITCH	S9.14	104°F	±2°F		D	2 SWS IN PARALLEL
970	C.E.C. TEMP HI-HI	TEMPERATURE SWITCH	S9.15	122°F	±2°F		D	2 SWS IN PARALLEL
972	C.E.C. TEMPERATURE LO	TEMPERATURE SWITCH	S9.21	40°F	±2°F		D	2 SWS IN PARALLEL
973	C.E.C. TEMPERATURE LO-LO	TEMPERATURE SWITCH	S9.22	32°F	±2°F		D	2 SWS IN PARALLEL
980	AIRCRAFT STROBE STATUS	RELAY	S9.16	-	-		D	

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Table 9.13 Command Signals

LINE NO.	COMMAND	COMMAND I.D.	OUTPUT		COMMENTS
			A	D	
990	ICE DETECTOR TEST BL. 1	C1.1		D	
1000	ICE DETECTOR TEST BL. 2	C1.2		D	
1010	A/P HYDRAULIC PUMP ON CMD	C2.4		D	
1020	"G" SWITCH BL. #1 TEST #1	C2.5		D	
1030	"G" SWITCH BL. #2 TEST #1	C2.6		D	
1040	"G" SWITCH BL. #1 TEST #2	C2.7		D	
1050	"G" SWITCH BL. #2 TEST #2	C2.8		D	
1060	"G" SWITCH DESET CMD BL. 1	C2.9		D	
1070	"G" SWITCH RESET CMD BL. 2	C2.10		D	
1080	TEETER BRAKE A-C PWR 'ON'	C2.11		D	
1090	TEETER HI FORCE BRAKES OFF	C2.12		D	
1100	AILERON CONTROL SET #1	C2.21	A		
1110	AILERON CONTROL SET #2	C2.22	A		
1120	AILERON CONTROL SET #3	C2.23	A		
1130	AILERON CONTROL SET #4	C2.24	A		
1140	ROTOR BRAKE CMD (STAGE 2 & HI SPEED)	C3.1		D	
1150	ROTOR BRAKE CMD (STAGE 1)	C3.2		D	
1160	TEETER LOW FORCE BRAKE CMD	C3.3		D	LOCAL CONTROL
1170	TEETER HI FORCE BRAKE CMD	C3.4		D	
1180	GEARBOX LUBE PUMP CMD	C4.1		D	
1190	ROTOR POSITIONER DRIVE CMD	C4.6		D	
1200	TURBINE READY CMD	C5.2		D	
1210	START/MOTOR CMD	C5.3		D	
1220	SYNCHRONIZE/GENERATE CMD	C5.4		D	
1230	TORQUE REF.	C5.5	A		
1240	VOLT/VAR REF.	C5.6	A		

Table 9.13 Command Signals (continued)

LINE NO.	COMMAND	COMMAND I.D.	OUTPUT		COMMENTS
			A	D	
1250	LOCKOUT RELAY CMD	C5.7		D	
1260	CYCLOCONVERTER TIE CLOSE	C5.8		D	
1270	CYCLOCONVERTER TIE TRIP	C5.9		D	
1280	YAW CW CMD	C6.1		D	
1290	YAW CCW CMD	C6.2		D	
1300	YAW MOTIVE BRAKE CMD	C6.3		D	
1310	YAW HOLDING BRAKE CMD	C6.4		D	
1320	YAW PUMP ENABLE	C6.5		D	
1330	FEATHER VALVE A-1 CMD	C7.3		D	FROM ESD ELECTRONICS
1340	FEATHER VALVE A-2 CMD	C7.4		D	
1350	ENABLE FEATHER VLV. A-1	C7.5		D	TO ESD ELECTRONICS
1360	ENABLE FEATHER VLV. A-2	C7.6		D	
1370	FEATHER VALVE B-1 CMD	C7.2		D	ACTIVATED DIRECTLY BY "G" SWITCH
1380	FEATHER VALVE B-2 CMD	C7.8		D	
1390	ENABLE ESD CMD	C9.1		D	

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Ice Detector

A Rosemount series 871 ice detector on each blade senses the accumulation of ice. The units were originally developed as an ice warning system for aircraft. They sense ice by detecting a change in the resonant frequency of a probe that is 0.25 in. in diameter and 1 in. long. The probe can detect as little as 0.015 in. of ice. On the MOD-5A, the units would be adjusted so that 0.2 ± 0.05 in. of ice will produce a 28 V signal. When ice is detected, a timer maintains the 28 V signal for 60 seconds while activating an internal heater in the ice detector, to melt ice on the probe. After 60 seconds, the heaters are disabled and the unit is ready to sense ice within 7 seconds of the first ice detection. If 0.2 ± 0.05 inches of ice accumulates before 60 seconds is up, the timer will reset for an another 60 seconds.

The units can operate at more than the 15g acceleration that they will experience during normal operation. The installation of the ice detectors is described in section 4.3.8.

Rotational Position

The sensors for blade teeter position, nacelle position and rotor shaft position are size 23, standard military 23 C x 6D, 60 Hz control transmitters (synchros). They are manufactured by the Vernitron Corporation. They are accurate to 6 minutes of arc. The output signal is converted to a signal with a range of 4 to 20 mA by Interface Engineering's model SA810-B synchro to linear DC converter.

Rotor Vibration

A tri-axial servo accelerometer, mounted on the bedplate near the gearbox, detects vibration in the rotor area. The unit is Model SA-307-TX, manufactured by Columbia Research Laboratories, Inc. Its volume is less than 24 in^3. It can detect vibrations over a range of ± 2.5g, with 0.2% accuracy over a frequency range from 0 to 300 Hz. The three analog signals are conditioned to provide a single discrete output by conditioning circuitry.

Rotational Speed

Wind turbine rotor speed is sensed by two Electro Corporation Di-Mag magnetic sensors sensing a 104 in. diameter "gear" with 360 teeth. The Di-Mag sensors combine, in a stainless steel shell, active electronics and a magnetic sensor to produce constant amplitude, fast rise and fall signals with noise immunity for the signal conditioning equipment.

The sensor and gear combination generate reliable output signals at speeds as low as 6 in. per second with a sensor/gear spacing of 0.1 in. Therefore, the sensor generates usable outputs for rotor speeds as low as 1.1 rpm.

The signal is conditioned to provide accuracy and rapid response. AIRPAX Corporation Tachtrol 3 digital tachometers condition the sensor signal. One tachometer covers speeds between 0 and 30 rpm and another tachometer covers speeds between 11.5 and 17.5 rpm, for greater resolution. The units contain relay set points that are inputs to the emergency shutdown subsystem. Some of the features of the Tachtrol 3 tachometers are:

- Power provided for active pickups (12V at 100 mA)
- Measures from 2 to 30 kHz
- 4 to 20 mA analog output
- Analog accuracy is ± 0.3% of the range
- Adjustable set point relays for overspeed emergency shutdown
- Analog and relay response times of two cycles of measured frequency + 30 msec.

G Switch

A device called the 'G switch' provides independent backup protection against overspeed. The G switches are positioned at 75% of the span in each blade. Each is adjusted to trip and electrically operate both feather valves if the steady state acceleration exceeds a preset level. This trip level indicates that the controller and emergency shutdown systems failed to trip and stop the rotor from an overspeed condition. The G switches feature a mechanically adjusted trip point of 18 to 24 g's. The trip condition actuates a single pole, double throw switch, which must be reset after it trips. The tripped switches are reset remotely by energizing the reset coil. The trip coil is energized remotely during start-up, to check the G switches and the feathering valves. This test checks both that the G switches don't trip prematurely, and that they do operate the feather valves. Using the manufacturer's calibration data, each G switch trip coil is energized to simulate an acceleration level just below the trip point. If neither unit causes the feather valve to operate, the simulated acceleration is increased until it just exceeds the trip point. The control logic checks that both G switches and the feather valves operate at this level.

9.3.2 SIGNAL CONDITIONING

The range for analog input to the controller is 4 to 20 mA. Discrete inputs must interrupt 120 Vac, 60 Hz, 6 mA signals. Signal conditioning is required for sensors or other inputs that do not meet these requirements.

In some cases, a control sensor also provides a signal to the engineering data system. These signals are buffered to prevent a fault in the engineering data system from affecting the control system. General Electric designed the signal conditioning discussed in the following paragraphs.

Rotational Position Signals

A purchased signal converter provides a 0 to 10 Vdc signal for rotational position. The signal is buffered and sent in parallel to the engineering data system and to 2 voltage-to-current converters. One converter provides a 4 to 20 mA output to the display and the other provides a 4 to 20 mA output to the controller. This circuit is illustrated in Figure 9-22.

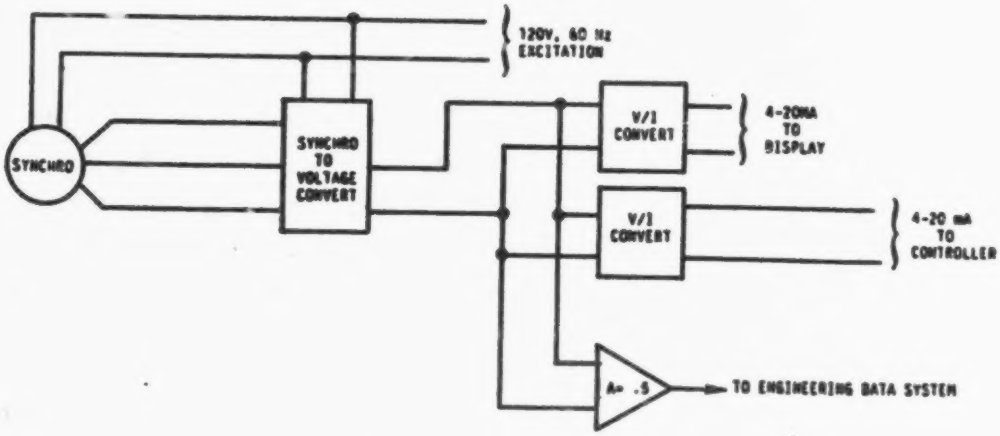

120V, 60 Hz
EXCITATION
SYNCHRO
SYNCHRO TO VOLTAGE CONVERT
V/I CONVERT
4-20MA TO DISPLAY
V/I CONVERT
4-20 mA TO CONTROLLER
A= .5
TO ENGINEERING DATA SYSTEM

Figure 9-22 Rotational Position Signal Circuit

Rotational Speed Signals

Conditioning of the aerodynamic rotor speed signal is provided by a purchased signal conditioner. It is discussed in Section 9.3.1.

The generator speed signal originates at a pulse generator on the wound rotor generator. The 240 pulses per revolution are converted to a linear DC voltage by a frequency-to-voltage converter. The signal is buffered, and sent to the engineering data system, to and voltage-to-current converters. This circuit is illustrated in Figure 9-23.

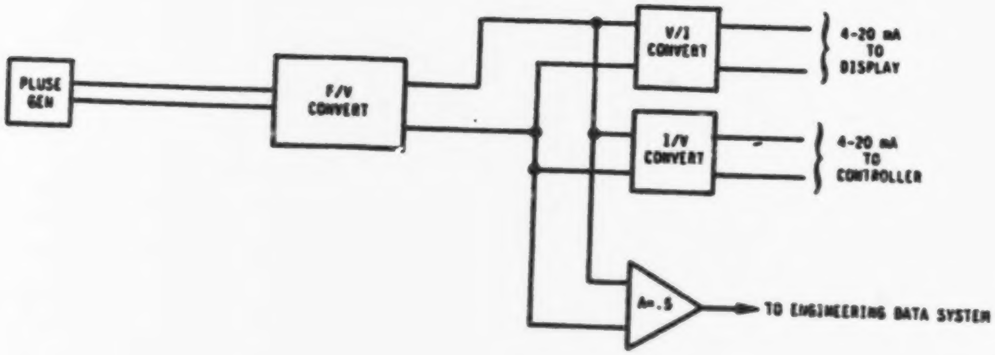
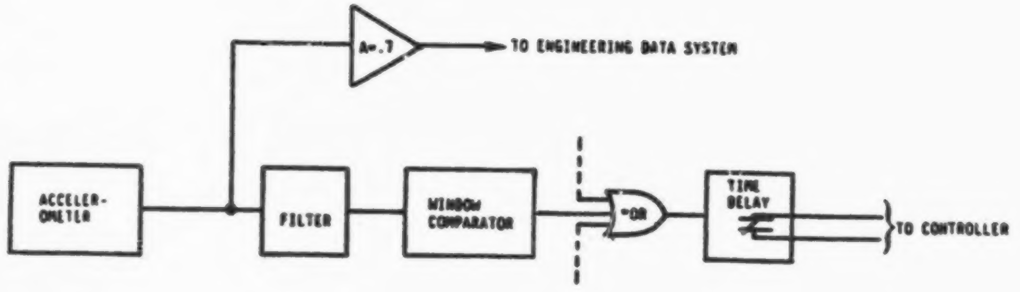

PLUSE GEN
F/V CONVERT
V/I CONVERT
I/V CONVERT
A=.5
4-20 mA TO DISPLAY
4-20 mA TO CONTROLLER
TO ENGINEERING DATA SYSTEM

Figure 9-23 Generator Speed Signal Circuit

Rotor Vibration Signals

The outputs from the accelerometer of the triaxial unit have a range of ±7.5/V. The conditioning circuit for each axis consists of a 0 to 40 Hz low pass filter, a window comparator with an adjustable trip point (±1.7g is used for the vertically oriented unit and ±0.7g for the horizontally oriented units), and an OR gate circuit which triggers a 200 msec delay for a single input to the controller. Each axis output signal is buffered before it enters the low pass filter, and sent to the engineering data system. This circuit is illustrated in Figure 9-24.


A=.7
TO ENGINEERING DATA SYSTEM
ACCELER-OMETER
FILTER
WINDOW COMPARATOR
*OR
TIME DELAY
TO CONTROLLER

* ORDERED WITH OTHER 2 ACCELEROMETERS

Figure 9-24 Rotor Vibration Signal Circuit

G Switch Test Signals

Commands for testing each G switch consist of constant current sources whose outputs are controlled by relays driven by the 120 Vac, 60 Hz discrete outputs of the system controller. The constant current sources can be adjusted to provide up to 100 mA. Test procedures for the G switches are discussed in 9.3.1. Figure 9-25 shows this circuit.

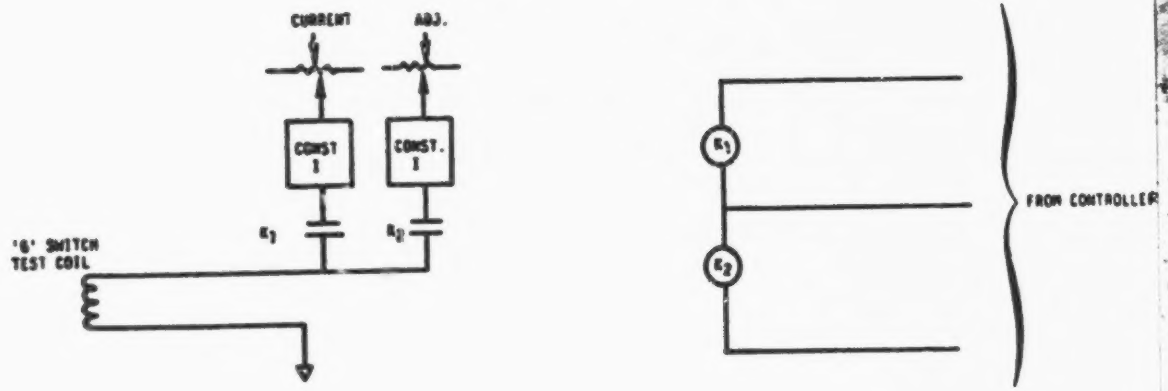

CURRENT
ADJ.
CONST I
CONST. I
K_1
K_2
'G' SWITCH TEST COIL
K_1
K_2
FROM CONTROLLER

Figure 9-25 G Switch Test Signals Circuit

Standard Signal Buffering

Some 4 to 20 mA signals are inputs to the engineering data system or the display. The signals are buffered to protect the control system against faults in the engineering data system or the display. The buffering circuit is illustrated in Figure 9-26.

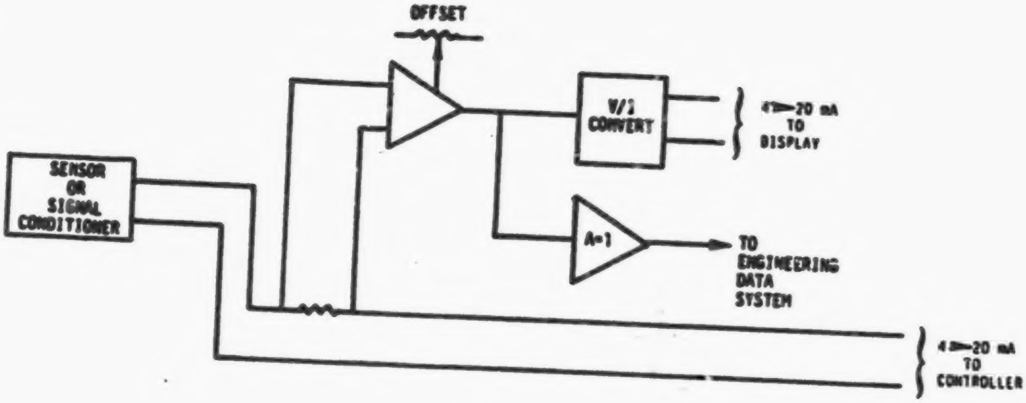

OFFSET
SENSOR OR SIGNAL CONDITIONER
V/I CONVERT
4→20 mA TO DISPLAY
A=1
TO ENGINEERING DATA SYSTEM
4→20 mA TO CONTROLLER

Figure 9-26 Standard Signal Buffering Circuit

9.4 ENGINEERING INSTRUMENTATION

The engineering data system collects and processes performance data while the system is being checked and during initial operation. The analog structural and electrical data is processed by the engineering instrumentation system. The controls data is processed by the controls data system. Figure 9-27 is a block diagram of the engineering data system.

The engineering instrumentation system comprises three remote multiplexer units mounted in the yoke, the nacelle, and on the ground. The units interface with a data van provided by NASA for recording data on magnetic tape and playback to a strip chart recorder.

The controls data system communicates with the controller through a two-way serial data interface. The controls data transmitted by the controller at eight bits per word, 50 words per message and one message per second at 1200 BAUD. Commands transmitted by the controls data system to the controller interrogate and alter the controller's RAM. Controls operating parameters may be adjusted at the site.

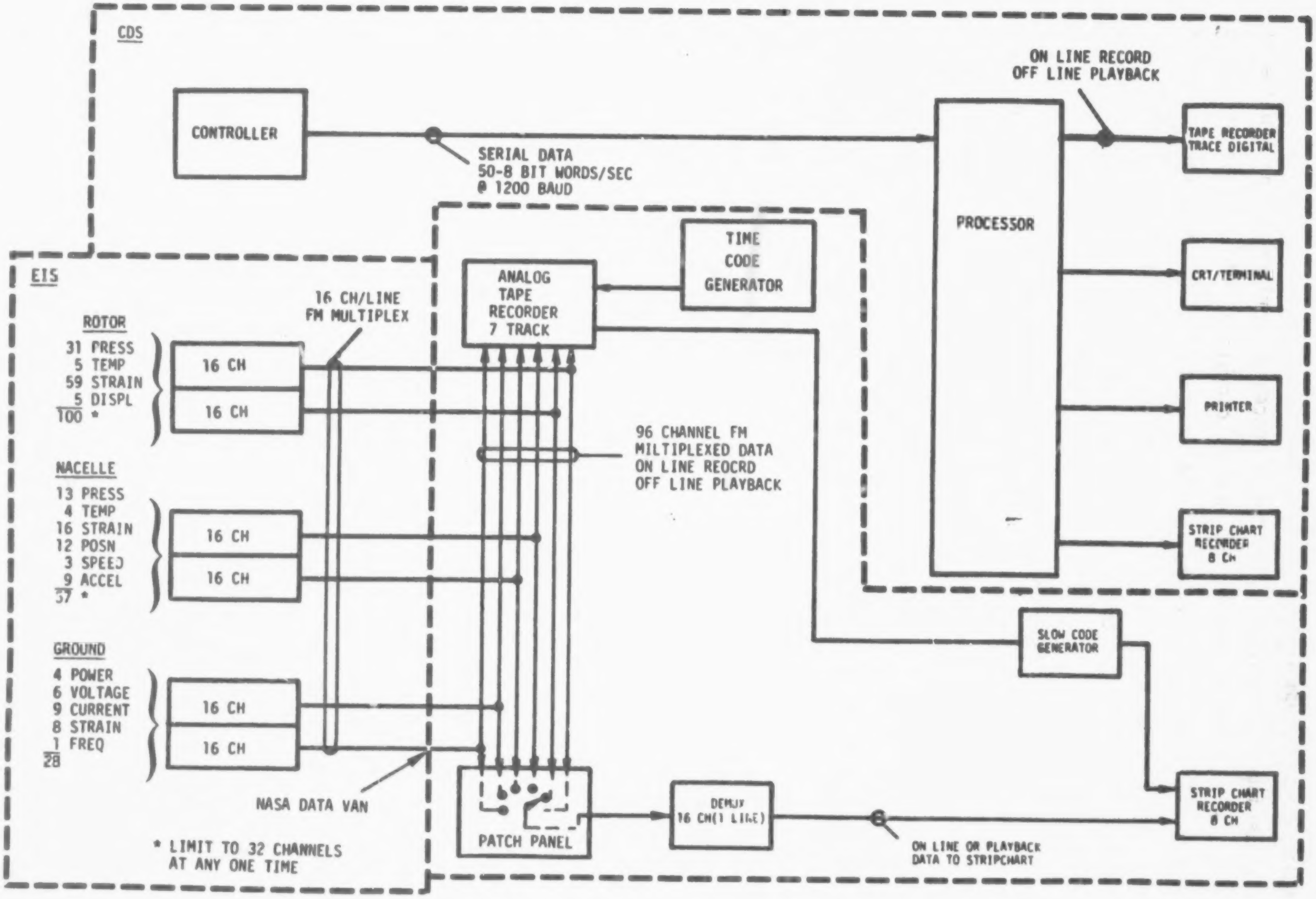

CDS
CONTROLLER
SERIAL DATA
50-8 BIT WORDS/SEC
@ 1200 BAUD
ON LINE RECORD
OFF LINE PLAYBACK
PROCESSOR
TAPE RECORDER
TRACE DIGITAL
CRT/TERMINAL
PRINTER
STRIP CHART
RECORDER
8 CH
EIS
ROTOR
31 PRESS
5 TEMP
59 STRAIN
5 DISPL
100 *
NACELLE
13 PRESS
4 TEMP
16 STRAIN
12 POSN
3 SPEED
9 ACCEL
37 *
GROUND
4 POWER
6 VOLTAGE
9 CURRENT
8 STRAIN
1 FREQ
28
16 CH
16 CH
16 CH
16 CH
16 CH
16 CH
16 CH/LINE
FM MULTIPLEX
NASA DATA VAN
* LIMIT TO 32 CHANNELS
AT ANY ONE TIME
ANALOG
TAPE
RECORDER
7 TRACK
TIME
CODE
GENERATOR
96 CHANNEL FM
MILTIPLEXED DATA
ON LINE REOCRD
OFF LINE PLAYBACK
PATCH PANEL
DEMUX
16 CH(1 LINE)
ON LINE OR PLAYBACK
DATA TO STRIPCHART
SLOW CODE
GENERATOR
STRIP CHART
RECORDER
8 CH

Figure 9-27 Engineering Data System

9.4.1 ENGINEERING INFORMATION SYSTEM

Engineering data is collected from the yoke, the nacelle and the electrical equipment building by remote multiplexing units. Each remote multiplexing unit accepts up to 32 dynamic inputs. The signals are multiplexed onto two subcarrier FM multiplexes for storage or analysis. They are demultiplexed and recorded on a strip chart recorder for real time observation. A schematic of this system is shown in Figure 9-28.

The data is sent to NASA's data van, or its equivalent, for recording and playback as shown by the blocks within the dashed lines of Figure 9-28.

All input signals to the engineering information system are analog and most are received directly from sensors. Some signals are used in the wind turbine control system as well as by the engineering information system. These signals are indicated on the instrumentation and control signal list by an 'X' in the column headed 'Shared by C.S. These signals are buffered before they are sent to the engineering information system to prevent the engineering information system from causing a control system failure.

Yoke Remote Multiplexing Unit

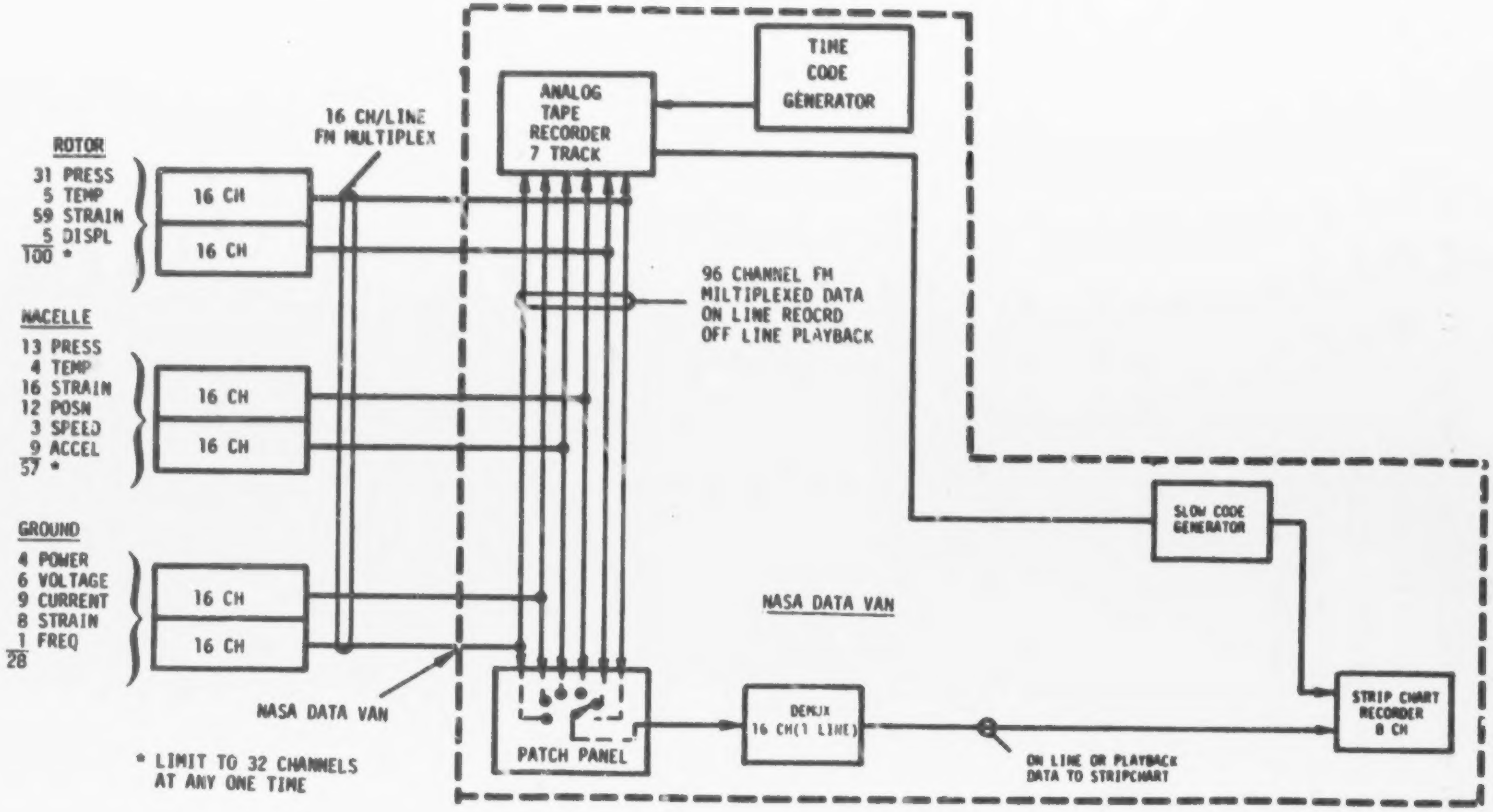
The signals that are to be monitored by the yoke remote multiplexing unit are shown in Table 9-14, which is listed as the rotor MUX. Since the total number of signals exceeds the capability of the multiplexor, a 'patch panel' is used to reassign the input signals periodically. In this way, redundant sensors are easily and quickly substituted for failed sensors or data from different sensors may be connected to verify other dubious readings.

Nacelle Remote Multiplexing Unit

The signals to be monitored by the nacelle remote multiplexing unit are listed in Table 9-15. The nacelle remote multiplexing unit also uses a 'patch panel' to accommodate more signals than the unit can process at one time.

Electrical Equipment Building Remote Multiplexing Unit

The signals received by the electrical equipment building remote multiplexing unit are shown in Table 9-16. A 'patch panel' is not required with this unit.



ROTOR
31 PRESS
5 TEMP
59 STRAIN
5 DISPL
100 *
NACELLE
13 PRESS
4 TEMP
16 STRAIN
12 POSN
3 SPEED
9 ACCEL
57 *
GROUND
4 POWER
6 VOLTAGE
9 CURRENT
8 STRAIN
1 FREQ
28
16 CH
16 CH
16 CH
16 CH
16 CH
16 CH
16 CH/LINE
FM MULTIPLEX
NASA DATA VAN
* LIMIT TO 32 CHANNELS
AT ANY ONE TIME
ANALOG
TAPE
RECORDER
7 TRACK
TIME
CODE
GENERATOR
96 CHANNEL FM
MILTIPLEXED DATA
ON LINE REOCRD
OFF LINE PLAYBACK
PATCH PANEL
DEMUX
16 CH(1 LINE)
NASA DATA VAN
SLOW CODE
GENERATOR
STRIP CHART
RECORDER
8 CH
ON LINE OR PLAYBACK
DATA TO STRIPCHART

Figure 9-28 Engineering Instrumentation System

Table 9-14 Signals Monitored by Yoke Remote Multiplexer

LINE NO.	COMMAND ITEM	SENSOR TYPE	COMMAND I.D.	RANGE	ACC'Y	OUTPUT A	OUTPUT D	COMMENTS
1400	BLADE 1 FLAP BEND @ 10%	STRAIN GAGES	ES1.1	4×10^{-3} IN/IN	±5%	A		
1410	BLADE 1 CHORD BEND @ 10%		ES1.2			A		
1420	BLADE 1 STRAIN @ 10%		ES1.3			A		
1430	BLADE 1 FLAP BEND @ 25%		ES1.4			A		
1440	BLADE 1 CHORD BEND @ 25%		ES1.5			A		
1450	BLADE 1 STRAIN @ 25%		ES1.6			A		
1460	BLADE 1 FLAP BEND @ 40%		ES1.7			A		
1470	BLADE 1 CHORD BEND @ 40%		ES1.8			A		
1480	BLADE 1 STRAIN @ 40%		ES1.9			A		
1490	BLADE 1 FLAP BEND @ 60%		ES1.10			A		
1500	BLADE 1 CHORD BEND @ 60%		ES1.11			A		
1510	BLADE 1 STRAIN @ 60%		ES1.12			A		
1520								
1530	BLADE 1 FLAP BEND @ 80%		ES1.45			A		
1540	BLADE 1 CHORD BEND @ 80%		ES1.46			A		
1550	BLADE 1 STRAIN @ 80%		ES1.47			A		
1560	ACTUATOR 1-1 STRAIN		ES1.48			A		
1570	LINK 1-1 STRAIN		ES1.49			A		
1580	AILERON 1-1 STRAIN		ES1.50			A		
1590	AILERON 1-1 FLAP BEND		ES1.51			A		
1600	AILERON 1-1 CHORD BEND	STRAIN GAGES	ES1.52	4×10^{-3} IN/IN	±5%	A		

Table 9-14 Signals Monitored by Yoke Remote Multiplexer (Cont'd)

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	RANGE	ACC'Y.	OUTPUT A	OUTPUT D	COMMENTS
1610	BLADE 2 FLAP BEND @ 10%	STRAIN GAGES	ES1.18	4×10^{-3} IN/IN	±5%	A		
1620	BLADE 2 CHORD BEND @ 10%		ES1.19			A		
1630	BLADE 2 STRAIN @ 10%		ES1.20			A		
1640	BLADE 2 FLAP BEND @ 25%		ES1.21			A		
1650	BLADE 2 CHORD BEND @ 25%		ES1.22			A		
1660	BLADE 2 STRAIN @ 25%		ES1.23			A		
1670	BLADE 2 FLAP BEND @ 40%		ES1.24			A		
1680	BLADE 2 CHORD BEND @ 40%		ES1.25			A		
1690	BLADE 2 STRAIN @ 40%		ES1.26			A		
1700	BLADE 2 FLAP BEND @ 60%		ES1.27			A		
1710	BLADE 2 CHORD BEND @ 60%		ES1.28			A		
1720	BLADE 2 STRAIN @ 60%		ES1.29			A		
1730	BLADE 2 FLAP BEND @ 80%		ES1.53			A		
1740	BLADE 2 CHORD BEND @ 80%		ES1.54			A		
1750	BLADE 2 STRAIN @ 80%		ES1.55			A		
1760	ACTUATOR 2-1 STRAIN		ES1.56			A		
1770	ACTUATOR 2-2 STRAIN		ES1.57			A		
1780	ACTUATOR 2-3 STRAIN		ES1.58			A		
1790	ACTUATOR 2-4 STRAIN		ES1.59			A		
1800	LINK 2-1 STRAIN		ES1.60			A		
1810	LINK 2-2 STRAIN		ES1.61			A		
1820	LINK 2-3 STRAIN		ES1.62			A		
1830	LINK 2-4 STRAIN		ES1.63			A		
1840	AILERON 2-1 STRAIN		ES1.64			A		
1850	AILERON 2-2 STRAIN		ES1.65			A		
1860	AILERON 2-3 STRAIN		ES1.66			A		
1870	AILERON 2-1 STRAIN	STRAIN GAGES	ES1.67	4×10^{-3} IN/IN	±5%	A		

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Table 9-14 Signals Monitored by Yoke Remote Multiplexer (Cont'd)

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	RANGE	ACC'Y.	OUTPUT		COMMENTS
						A	D	
1880	TEETER BRAKE PRESS. HI PRESS.	PRESSURE TRANSDUCER	ES2.11	0 → 5000 PSI	±2%	A		
1890	TEETER BRAKE PRESS. LOW PRESS.	PRESSURE TRANSDUCER	ES2.12	0 → 5000 PSI	±2%	A		
1900	RHP PUMP DISCHARGE PRESS	PRESSURE TRANSDUCER	ES2.13	0 → 5000 PSI	±2%	A		
1910	RHP MAIN ACCUMULATOR PRESS	PRESSURE TRANSDUCER	ES2.14	0 → 5000 PSI	±2%	A		
1920	RHP PUMP DISCHARGE TEMP	RTD	ES2.15	0°F → 200°F	±5%	A		
1930	ACTUATOR EXTEND PRESS 1-1	PRESSURE TRANSDUCER	ES2.16	0 → 5000 PSI	±2%	A		
1940	ACTUATOR RETRACT PRESS 1-1	↓	ES2.17	↓	↓	A		
1950	EMER. FEATHER ACCUM PRESS 1-1	↓	ES2.18	↓	↓	A		
1960	ACTUATOR EXTEND PRESS 1-2	↓	ES2.19	↓	↓	A		
1970	ACTUATOR RETRACT PRESS 1-2	↓	ES2.20	↓	↓	A		
1980	EMER. FEATHER ACCUM PRESS 1-2	↓	ES2.21	↓	↓	A		
1990	ACTUATOR EXTEND PRESS 1-3	↓	ES2.22	↓	↓	A		
2000	ACTUATOR RETRACT PRESS 1-3	↓	ES2.23	↓	↓	A		
2010	EMER. FEATHER ACCUM PRESS 1-3	↓	ES2.24	↓	↓	A		
2020	ACTUATOR EXTEND PRESS 1-4	↓	ES2.25	↓	↓	A		
2030	ACTUATOR RETRACT PRESS 1-4	↓	ES2.26	↓	↓	A		
2040	EMER. FEATHER ACCUM PRESS 1-4	↓	ES2.27	↓	↓	A		
2050	ACTUATOR EXTEND PRESS 2-1	↓	ES2.28	↓	↓	A		
2060	ACTUATOR RETRACT PRESS 2-1	↓	ES2.29	↓	↓	A		
2070	EMER. FEATHER ACCUM PRESS 2-1	↓	ES2.30	↓	↓	A		
2080	ACTUATOR EXTEND PRESS 2-2	↓	ES2.31	↓	↓	A		
2090	ACTUATOR RETRACT PRESS 2-2	↓	ES2.32	↓	↓	A		
2100	EMER. FEATHER ACCUM PRESS 2-2	↓	ES2.33	↓	↓	A		
2110	ACTUATOR EXTEND PRESS 2-3	↓	ES2.34	↓	↓	A		
2120	ACTUATOR RETRACT PRESS 2-3	PRESSURE TRANSDUCER	ES2.35	0 → 5000 PSI	±2%	A		

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Table 9-14 Signals Monitored by Yoke Remote Multiplexer (Cont'd)

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	RANGE	ACC'Y.	OUTPUT A	OUTPUT D	COMMENTS
2130	EMER. FEATHER ACCUM PRESS 2-3	PRESSURE TRANSDUCER	ES2.36	0 - 5000 PSI	±2%	A		
2140	ACTUATOR EXTEND PRESS 2-4		ES2.37			A		
2150	ACTUATOR RETRACT PRESS 2-4		ES2.38			A		
2160	EMER. FEATHER ACCUM PRESS 2-4		ES2.39			A		
2170	PILOT PRESS. BL. 1		ES2.40			A		
2180	PILOT PRESS BL. 2		ES2.41	0 - 5000 PSI		A		
2190	HHP RESERVOIR PRESS	PRESSURE TRANSDUCER	ES2.42	0 - 50 PSI	±2%	A		
2200	TEETER RADIAL BRNG. TEMP. +Y	RTD	ES3.1	-40 - +150°F	±2%	A		
2210	TEETER THRUST BRNG. TEMP. +Y	RTD	ES3.2	-40 - +150°F	±2%	A		
2220	TEETER RADIAL BRNG. TEMP. -Y	RTD	ES3.3	-40 - +150°F	±2%	A		
2230	TEETER THRUST BRNG. TEMP. -Y	RTD	ES3.4	-40 - +150°F	±2%	A		
2240	TEETER SHAFT RADIAL DISPL. ±Z @ +Y	LVDT	ES3.5	±0.5 in.	±2%	A		
2250	TEETER SHAFT RADIAL DISPL. ±X @ +Y	LVDT	ES3.6	±0.5 in.	±2%	A		
2260	TEETER SHAFT RADIAL DISPL. ±Z @ -Y	LVDT	ES3.7	±0.5 in.	±2%	A		
2270	TEETER SHAFT RADIAL DISPL. ±X @ -Y	LVDT	ES3.8	±0.5 in.	±2%	A		
2280	TEETER SHAFT AXIAL DISPL. ±Y @ +Y	LVDT	ES3.9	±0.5 in.	±2%	A		
2290	ROTOR SHAFT STRAIN	STRAIN GAGES	ES3.10	11 x 10^{-6} IN/IN	±5%	A		
2300	YOKE STRAIN #1		ES3.11			A		
2310	YOKE STRAIN #2		ES3.12			A		
2320	YOKE STRAIN #3		ES3.13			A		
2330	YOKE STRAIN #4		ES3.14			A		
2340	YOKE STRAIN #5		ES3.15			A		
2350	YOKE STRAIN #6		ES3.16			A		
2360	YOKE STRAIN #7		ES3.17			A		
2370	YOKE STRAIN #8	STRAIN GAGES	ES3.18	11 x 10^{-6} IN/IN	±5%	A		

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Table 9-14 Signals Monitored by Yoke Remote Multiplexer (Cont'd)

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	RANGE	ACC'Y.	OUTPUT		COMMENTS
						A	D	
2380	YOKE STRAIN #9	STRAIN GAGES	ES3.19	11 x 10^{-6} IN/IN	±5%	A		
2390	YOKE STRAIN #10	↓	ES3.20	↓	↓	A		
2400	YOKE STRAIN #11	↓	ES3.21	↓	↓	A		
2410	YOKE STRAIN 12	STRAIN GAGES	ES3.22	11 x 10^{-6} IN/IN	±5%	A		

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Table 9-15 Signals Monitored by Nacelle Remote Multiplexer

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	SHARED BY C.S.	RANGE	ACC'Y.	OUTPUT		COMMENTS
							A	B	
2420	HUB SPEED	MAGNETIC	ES3.23	X	0 - 30 RPM	± 1%	A		
2430	GENERATOR SPEED	MAGNETIC	ES5.1	X	0 - 2300 RPM	± 1%	A		
2440	TEETER ANGLE	SYNCHRO	ES2.24	X	±12°	± 2%	A		
2450	LUBE RESV. TEMP.	RTD	ES4.1		0 - 200°F	± 2%	A		
2460	LUBE PUMP PRESS., MOT.	PRESSURE TRANSDUCER	ES4.2		0 - 300 PSI	± 2%	A		
2470	LUBE PUMP PRESS., SHAFT	PRESSURE TRANSDUCER	ES4.3		0 - 300 PSI	± 2%	A		
2480	LUBE SUPPLY PRESSURE	PRESSURE TRANSDUCER	ES4.4		0 - 300 PSI	± 2%	A		
2490	LUBE SUPPLY TEMP.	RTD	ES4.5		0 - 200°	± 2%	A		
2500	MOTIVE ACCUM. PRESS.	PRESSURE TRANSDUCER	ES6.1		0 - 5000 PSI	± 2%	A		
2510	BRAKE ACCUM. PRESS.	↓	ES6.2		0 - 3000 PSI	± 2%	A		
2520	YAW ACT. SUPPLY PRESS	↓	ES6.3		0 - 5000 PSI	± 2%	A		
2530	YAW ACT. RETURN PRESS	↓	ES6.4		0 - 5000 PSI	± 2%	A		
2540	YAW MOTIVE BRAKE PRESS	↓	ES6.5		0 - 3000 PSI	± 2%	A		
2550	YAW HOLDING BRAKE PRESS.	↓	ES6.6		0 - 3000 PSI	± 2%	A		
2560	ROTOR HOLDING BRAKE PRESS (H.S. SHAFT)	↓	ES6.7		0 - 3000 PSI	± 2%	A		
2570	ROTOR HOLDING BRAKE PRESS. (STG. 2)	↓	ES6.15		0 - 3000 PSI	± 2%	A		
2580	ROTOR HOLDING BRAKE PRESS. (STG. 1)	↓	ES6.16		0 - 3000 PSI	± 2%	A		
2590	ROTOR BRAKE ACCUM. PRESS.	PRESSURE TRANSDUCER	ES6.17		0 - 3000 PSI	± 2%	A		
2600	NACELLE VIBRATION 1 (X)	ACCELEROMETER	ES9.1		±2.5g	±1%	A		1 TRIAX MOUNT
2610	NACELLE VIBRATION 1 (Y)	↓	ES9.2		±2.5g	±1%	A		
2620	NACELLE VIBRATION 1 (Z)	↓	ES9.3		±2.5g	±1%	A		
2630	NACELLE VIBRATION 2 (X)	↓	ES9.4		±2.5g	±1%	A		1 TRIAX MOUNT
2640	NACELLE VIBRATION 2 (Y)	↓	ES9.5		±2.5g	±1%	A		
2650	NACELLE VIBRATION 2 (Z)	ACCELEROMETER	ES9.6		±2.5g	±1%	A		

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Table 9-15 Signals Monitored by Nacelle Remote Multiplexer (Cont'd)

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	SHARED BY C.S.	RANGE	ACC'Y.	OUTPUT A	OUTPUT B	COMMENTS
2660	NACELLE VIBRATION 3 (X)	ACCELEROMETER	ES9.7		±2.5g	±1%	A		
2670	NACELLE VIBRATION 3 (Y)	↓	ES9.8		±2.5g	±1%	A		1 TRIAX MOUNT
2680	NACELLE VIBRATION 3 (Z)	ACCELEROMETER	ES9.9		±2.5g	±1%	A		
2690	AILERON POSITION 1-1	LVDT	ES1.37	X	0 → 10 IN.	±.03 IN	A		
2700	1-2	↓	ES1.38	X	↓	↓	A		
2710	1-3	↓	ES1.39	X	↓	↓	A		
2720	1-4	↓	ES1.40	X	↓	↓	A		
2730	2-1	↓	ES1.41	X	↓	↓	A		
2740	2-2	↓	ES1.42	X	↓	↓	A		
2750	2-3	↓	ES1.43	X	↓	↓	A		
2760	AILERON POSITION 2-4	LVDT	ES1.44	X	0 → 10 IN.	±.03 IN	A		
2770	WIND SPEED	D-C MAGNETO	ES9.10	X	0 → 150 MPH	±2 MPH	A		
2780	YAW ERROR	SYNCHRO	ES9.11	X	0 → 540°	±2°	A		
2790	NACELLE STRAIN 1	STRAIN GAGES	ES9.12		6.6 x 10^{-4} IN/IN	±5%	A		
2800	2	↓	ES9.13		↓	↓	A		
2810	3	↓	ES9.14		↓	↓	A		
2820	4	↓	ES9.15		↓	↓	A		
2830	5	↓	ES9.16		↓	↓	A		
2840	6	↓	ES9.17		↓	↓	A		
2850	7	↓	ES9.18		↓	↓	A		
2860	8	↓	ES9.19		↓	↓	A		
2870	9	↓	ES9.20		↓	↓	A		
2880	NACELLE STRAIN 10	STRAIN GAGES	ES9.21		6.6 x 10^{-4} IN/IN	±5%	A		

Table 9-15 Signals Monitored by Nacelle Remote Multiplexer (Cont'd)

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	SHARED BY C.S.	RANGE	ACC'Y.	OUTPUT A	OUTPUT D	COMMENTS
2890	YAW HOUSING STRAIN 1	STRAIN GAGES	ES6.8		6.6 x 10^{-6} IN/IN	±5%	A		
2900	2		ES6.9				A		
2910	3		ES6.10				A		
2920	4		ES6.11				A		
2930	5		ES6.12				A		
2940	YAW HOUSING STRAIN 6	STRAIN GAGES	ES6.13		6.6 x 10^{-6} IN/IN	±5%	A		
2950	ROTOR POSITION	SYNCHRO	ES3.75	X	0 - 360°	±1%	A		
2960	YAW POSITION	SYNCHRO	ES6.14	X	0 - 360°	±1%	A		
2970	NACELLE AMBIENT TEMPERATURE	RTD	ES9.30		-40° - 150°F	±2%	A		
2980	NACELLE OUTSIDE AMB. TEMP.	RTD	ES9.31		-40° - 150°F	±2%	A		

Table 9-16 Signals Received by the Electrical Equipment Remote Multiplexer

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	SHARED BY C.S.	RANGE	ACC'Y.	OUTPUT A	OUTPUT D	COMMENTS
2990	BUS VOLTAGE (ØA-ØB)	TRANSDUCER	ES8.1		0 → 5 KV	±0.5%	A		
3000	BUS VOLTAGE (ØB-ØC)	↓	ES8.2		0 → 5 KV	↓	A		
3010	BUS VOLTAGE (ØC-ØA)	↓	ES8.3		0 → 5 KV	↓	A		
3020	BUS CURRENT (ØA)	↓	ES8.4		0 → 1200 A	↓	A		
3030	BUS CURRENT (ØB)	↓	ES8.5		0 → 1200 A	↓	A		
3040	BUS CURRENT (ØC)	↓	ES8.6		0 → 1200 A	↓	A		
3050	BUS POWER (KW)	↓	ES8.7	X	-.5 → 10 MW	↓	A		
3060	BUS POWER (KVAR)	↓	ES8.8	X	-.5 → 10 MVAR	↓	A		
3070	CYCLOCONVERTER CURRENT (ØA)	↓	ES8.9		0 → 500 A	↓	A		
3080	CYCLOCONVERTER CURRENT (ØB)	↓	ES8.10		0 → 500 A	↓	A		
3090	CYCLOCONVERTER CURRENT (ØC)	↓	ES8.11		0 → 500 A	↓	A		
3100	STATOR VOLTAGE (ØA-ØB)	↓	ES8.12		0 → 5 KV	↓	A		
3110	STATOR VOLTAGE (ØB-ØC)	↓	ES8.13		0 → 5 KV	↓	A		
3120	STATOR VOLTAGE (ØC-ØA)	↓	ES8.14		0 → 5 KV	↓	A		
3130	STATOR CURRENT (ØA)	↓	ES8.15		-500 → 1200 A	↓	A		
3140	STATOR CURRENT (ØB)	↓	ES8.16		-500 → 1200 A	↓	A		
3150	STATOR CURRENT (ØC)	↓	ES8.17		-500 → 1200 A	↓	A		
3160	STATOR POWER (KW)	↓	ES8.18		-.5 → 10 MW	↓	A		
3170	STATOR POWER (KVAR)	↓	ES8.19		-.5 → 10 MVAR	↓	A		
3180	STATOR FREQUENCY	TRANSDUCER	ES8.20		55 → 65 HZ	±0.5%	A		
3190	TOWER STRAIN AXIS 1	STRAIN GAGES	ES9.22		$R \times 10^{-6}$ IN/IN	±5%	A		HEIGHT 1
3200	TOWER STRAIN AXIS 2	↓	ES9.23		↓	↓	A		
3210	TOWER STRAIN AXIS 1	↓	ES9.24		↓	↓	A		HEIGHT 2
3220	TOWER STRAIN AXIS 2	STRAIN GAGES	ES9.25		$R \times 10^{-6}$ IN/IN	±5%	A		

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Table 9-16 Signals Received by the Electrical Equipment Remote Multiplexer (Cont'd)

LINE NO.	MEASURED ITEM	SENSOR TYPE	SIGNAL I.D.	SIGNED BY C.S. RANGE	ACC'Y.	OUTPUT A	OUTPUT B	COMMENTS
3230	TOWER STRAIN AXIS 1	STRAIN GAGES	ES9.26	8×10^{-6} IN/IN	±5%	A		HEIGHT 3
3240	TOWER STRAIN AXIS 2	↓	ES9.27	↓	↓	A		
3250	TOWER STRAIN AXIS 1	↓	ES9.28	↓	↓	A		HEIGHT 4
3260	TOWER STRAIN AXIS 2	STRAIN GAGES	ES9.29	8×10^{-6} IN/IN	±5%	A		

9.4.2 CONTROLS DATA SYSTEM

The controls data system is located on the ground near the base of the tower. It interfaces with the control system controller, which is located in the nacelle, via asynchronous serial communications. Controller operating data is received by the controls data system and processed in real time to provide the following functions:

- generate a magnetic tape record of the data
- selectively display analog data on a strip chart recorder
- compute data to be summarized by a line printer.

The operator's commands are transmitted to the controller to request a listing of the contents of the RAM and to alter the contents of the RAM.

The controls data system consists of a processor, tape recorder, CRT terminal, line printer, and a strip chart recorder. A block diagram is shown in Figure 9-29. Analog Devices, Inc. supplies the processor, CRT terminal and line printer. The processor is a MACSYM 150 with a monitor. The line printer is a PNT05-0100, 80 column printer, which is an accessory for the MACSYM. The tape recorder is a GPIB-1050 by Innovative Data Technology. The strip chart recorder had not been specified when design activity was suspended.

The serial communications is 20 mA at 1200 BAUD. The format for the serial data is listed in Table 9-17.

An eight bit data word is transmitted in two serial words. The data word D_7 D_6 D_5 D_4 D_3 D_2 D_1 D_0 is transmitted by the serial data words 0011 D_7 D_6 D_5 D_4 and 0011 D_3 D_2 D_1 D_0. The serial header word is 0011 0011 and the serial trailer word is 0000 1101.

The I/O data, as implemented in the development system, is listed in Table 9-18. The list would have been expanded if the project had not been terminated.

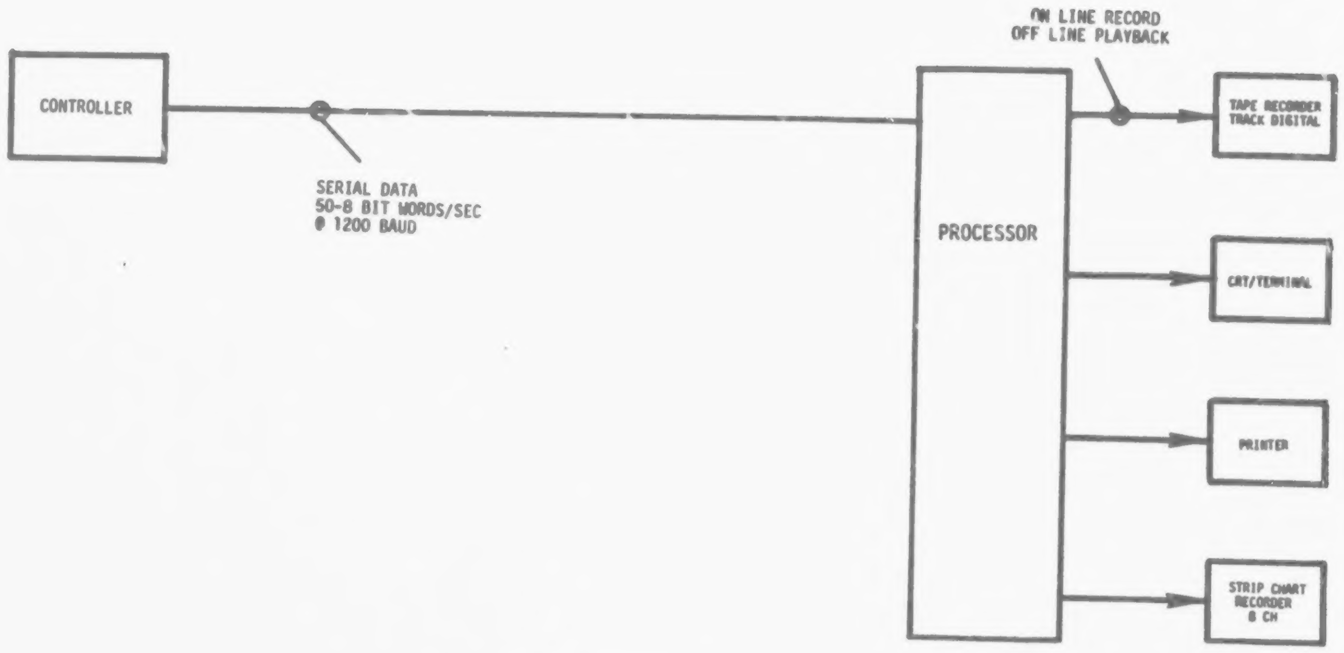
ON LINE RECORD
OFF LINE PLAYBACK
CONTROLLER
SERIAL DATA
50-8 BIT WORDS/SEC
@ 1200 BAUD
PROCESSOR
TAPE RECORDER
TRACK DIGITAL
CRT/TERMINAL
PRINTER
STRIP CHART
RECORDER
8 CH

Figure 9-29 Controls Data System Block Diagram

Table 9-17

Serial Data Sequence

SEQUENCE		SERIAL WORDS
o HEADER		1
o IDENTIFICATION		2
o I/O DATA		82
o ALARMS		4
o RAM		8
o CHECK SUM		4
o TRAILER		1
	TOTAL	102

Table 9-18
I/O Data List

DATA WORD	BIT	SIGNAL	FUNCTION
1	0	S1A1	ICE DETECTION BLADE #1
	1	S1A2	ICE DETECTION BLADE #2
	2	S1A3	HIGH TEMPERATURE BLADE #1
	3	S1A4	HIGH TEMPERATURE BLADE #2
	4	S1A5	HIGH STRAIN BLADE #1
	5	S1A6	HIGH STRAIN BLADE #2
	6	S2A3	ROTOR HYDRAULICS LEVEL
	7	S2A4	ROTOR HYDRAULICS OIL FILTER
2	0	S2A5	ROTOR HYDRAULICS OIL TEMPERATURE
	1	S2A14	ROTOR HYDRAULICS ACCUMULATOR PRESSURE
	2	S2A6	ROTOR HYDRAULICS PUMP PRESSURE
	3	S2A30	AILERON LATCHES
	4	S2A31	AILERON PRESSURES
	5	S2A7	TEETER BRAKE ACCUMULATOR PRESSURE
	6	S2A12	TEETER BRAKE HIGH FORCE SOLENOID ON
	7	S3A3	ROTOR VIBRATION
3	0	S3A11	ROTOR POSITIONER DRIVE
	1	S3A1	ROTOR BRAKE HIGH SPEED SHAFT
	2	S3A12	ROTOR BRAKE LOW SPEED SHAFT STAGE 1
	3	S3A13	ROTOR BRAKE LOW SPEED SHAFT STAGE 2
	4	S3A14	ROTOR BRAKE ACCUMULATOR PRESSURE
	5	S4A11	LUBE RESERVOIR LEVEL
	6	S4A26	LUBE RESERVOIR HIGH TEMPERATURE
	7	S4A27	LUBE RESERVOIR LOW TEMPERATURE

Table 9-18 (Continued)

I/O Data List

DATA WORD	BIT	SIGNAL	FUNCTION
4	0	S4A28	LUBE SUPPLY TEMPERATURE HIGH
	1	S4A29	LUBE SUPPLY TEMPERATURE HIGH-HIGH
	2	S4A23	LUBE SUPPLY PRESSURE "A"
	3	S4A24	LUBE SUPPLY PRESSURE "B"
	4	S4A25	LUBE SUPPLY PRESSURE "C"
	5	S4A14	LUBE SUPPLY FILTER
	6	S4A30	SHAFT LUBE PUMP PRESSURE
	7	S5A6	GENERATOR RESERVOIR LUBE LEVEL
5	0	S5A7	GENERATOR RESERVOIR LUBE TEMPERATURE
	1	S5A2	GENERATOR LUBE PRESSURE
	2	S5A8	GENERATOR BEARING TEMPERATURE
	3	S5A1	GENERATOR WINDING TEMPERATURE
	4	S5A3	GENERATOR VIBRATION
	5	S6A8	YAW FILTER STATUS
	6	S6A9	YAW HOLDING BRAKE STATUS
	7	S6A10	YAW GRIPPER STATUS
6	0	S6A2	YAW HOLDING BRAKE ACCUMULATOR PRESSURE
	1	S6A13	YAW MAIN ACCUMULATOR PRESSURE
	2	S6A3	YAW OIL LEVEL
	3	S6A12	YAW OIL TEMPERATURE
	4	S6A4	+Z CYLINDERS CW POSITION
	5	S6A5	+Z CYLINDERS CCW POSITION
	6	S6A6	-Z CYLINDERS CW POSITION
	7	S6A7	-Z CYLINDERS CCW POSITION

Table 9-18 (Continued)

I/O Data List

DATA WORD	BIT	SIGNAL	FUNCTION
7	0	S7A4	ESD SYSTEM READY
	1	S7A13	FEATHER VALVE A-1 CMD STATUS
	2	S7A14	FEATHER VALVE A-2 CMD STATUS
	3	S8A1	LOCKOUT RELAY STATUS
	4	S8A3	STATOR TIE STATUS
	5	S8A4	STATOR SHORT STATUS
	6	S8A5	CYCLOCONVERTER TIE STATUS
	7	S8A2	CONVERTER READY
8	0	S8A6	UTILITY POWER PRESENT
	1	S9A1	INTRUSION ALARM
	2	S9A2	OIS/EIS STATUS
	3	S9A3	CHARGER STATUS
	4	S9A10	UPS BATTERY STATUS
	5	S9A11	UPS INVERTER STATUS
	6	S9A17	MANUAL KEY SWITCH
	7	S9A18	LOCKOUT KEY SWITCH
9	0	S9A19	AUTOMATIC KEY SWITCH
	1	S9A20	RESET KEY SWITCH
	2	S9A12	NACELLE FIRE ALARM
	3	S9A13	C.E.C. AIR FLOW
	4	S9A14	C.E.C. TEMPERATURE HIGH
	5	S9A15	C.E.C. TEMPERATURE HIGH-HIGH
	6	S9A21	C.E.C. TEMPERATURE LOW
	7	S9A22	C.E.C. TEMPERATURE LOW-LOW

Table 9-18 (Continued)

I/O Data List

DATA WORD	BIT	SIGNAL	FUNCTION
10	0	S9A16	AIRCRAFT STROBE STATUS
	1	C1A1	ICE DETECTOR TEST BLADE #1
	2	C1A2	ICE DETECTOR TEST BLADE #2
	3	C2A4	ROTOR HYDRAULIC PUMP ON CMD
	4	C2A25	G SWITCH TEST ENABLE
	5	C2A26	G SWITCH BLADE #1
	6	C2A27	G SWITCH BLADE #2
	7	C2A28	G SWITCH TEST #1
11	0	C2A29	G SWITCH TEST #2
	1	C2A30	G SWITCH RESET CMD
	2	C2A11	TEETER BRAKE A-C POWER ON
	3	C2A12	TEETER HIGH FORCE BRAKES OFF
	4	C3A1	ROTOR BRAKE (STAGE 2 AND HIGH SPEED)
	5	C3A2	ROTOR BRAKE (STAGE 1)
	6	C4A1	GEARBOX LUBE PUMP CMD
	7	C4A6	ROTOR POSITIONER DRIVE CMD
12	0	C5A2	TURBINE READY CMD
	1	C5A3	START/MOTOR CMD
	2	C5A4	SYNCHRONIZE/GENERATE CMD
	3	C5A7	LOCKOUT RELAY CMD
	4	C5A8	CYCLOCONVERTER TIE CLOSE
	5	C5A9	CYCLOCONVERTER TIE TRIP
	6	C6A1	YAW CW CMD
	7	C6A2	YAW CCW CMD
13	0	C6A3	YAW MOTIVE BRAKE CMD
	1	C6A4	YAW HOLDING BRAKE CMD
	2	C6A5	YAW PUMP ENABLE
	3	C7A5	ENABLE FEATHER VALVE A-1
	4	C7A6	ENABLE FEATHER VALVE A-2
	5	C9A1	ENABLE ESD CMD

Table 9-18 (Continued)

I/O Data List

DATA WORD	SIGNAL	FUNCTION
14	S2A21	AILERON POSITION #1
15	S2A23	AILERON POSITION #2
16	S2A18	TEETER ANGLE
17	S3A4	ROTOR SPEED (0 - 30 RPM)
18	S5A9	GENERATOR SPEED
19	S5A5	GENERATED POWER
20	S9A4	WIND SPEED #1
21	S9A5	YAW ERROR #1
22	S9A6	WIND SPEED #2
23	S9A7	YAW ERROR #2
24	C2A21	AILERON CONTROL SET #1
25	C2A24	AILERON CONTROL SET #4
26	C5A5	GENERATOR REFERENCE

9.5 WIND TURBINE SIMULATOR

The basic function of the simulator is to test and check the controller. The simulator interfaces with the controller, receiving the controller command outputs, simulating the wind turbine's response to the commands in accordance with operator-selected external parameters, and providing the corresponding signals to the controller sensor inputs.

The simulator processes inputs from the controller and the operator to provide responses to the controller that will exercise the controller as it will be exercised during the operation of the wind turbine generator.

The simulator generates the wind speed and direction error signals. The wind speed can be selected by the operator to provide:

- steady state speed,
- sinusoidal cosine wind gust with variable amplitude and period,
- random speed variations in a selected amplitude range.

The wind direction relative to the nacelle position is indicated as an yaw error. The initial yaw error is selected by the operator. When yaw control is activated, the simulator calculates the yaw error modification in response to the yaw correction commands issued by the controller.

The simulator calculates the rotor torques as a function of rotor speed, wind velocity, and aileron control angle. The rotational dynamics are calculated from the torque and the electrical power generated using a model with two degrees of freedom.

The aileron control actuators are modeled as time constants.

The logic functions of the simulator, the wind model, the torque calculations, and yaw control are implemented in software. The aileron actuator time constants, the rotational dynamics, and electrical power generation are implemented by analog computing hardware.

The simulator signal outputs to the controller are of five basic types. They are:

- Discrete signals that are independent of system operation, and are the result of a system anomaly or are generated by the operator.
- Discrete signals that in normal operation would change state as a result of a controller output command.
- Analog signals that represent a dynamic response to controller output commands.
- Analog signals that represent external parameters. These signals would be controlled by the operator in accordance with the test operation.
- Site and remote operator commands transmitted via serial data communications.

The simulator signal inputs from the controller are of three basic types. They are:

- Discrete signals that are on/off commands issued by the controller.
- Analog signals that are position commands issued by the controller.
- All operating data transmitted via serial data communications.

9.5.1 SIMULATOR HARDWARE

The simulator is a MACSYM programmable controller, made by Analog Devices, Inc. The analog computing function is assembled on blank cards and inserted into the simulator card chassis.

The simulator's I/O requirements are the same as the controller's I/O requirements. The simulator signal input and command output corresponds to the controller command output and signal input respectively. The simulator hardware specification is given in Table 9-19.

Table 9-19

WIND TURBINE GENERATOR SIMULATOR SPECIFICATION

o MAC02-21 128K MEMORY CRT KEYBOARD CARTRIDGE TAPE RTC ADIO CONTROLLER	
o (3) AOC06	4 CHANNEL 4-20 mA OUTPUT
o (I) AIM03-011	16 CHANNEL 4-20 mA INPUT
o (5) DIO-01	16 CHANNEL DIGITAL I/O
o (15) IA140-04	4 PK 140VAC/10 mA INPUT
o (6) OA140-04	4 PK 140 VAC/3A OUTPUT
o (1) ACP04	4 CHANNEL 20 mA SERIAL PORT
o ANALOG COMPUTING CARD	

The aileron actuator block diagram is shown in Figure 9-30. It computes the following function:

$\delta_a = \delta_c \, ({}^{1}/1+\tau S)$
δ_a = actuator output angle
δ_c = controller position command
τ = actuator time constant

The block diagram for the rotational dynamic and electric power generation is shown in Figure 9-31 and computes the following equations:

$$\ddot{\theta}_R = \frac{\tau_R}{J_R} + \frac{C}{J_R}(\dot{\theta}_R - \dot{\theta}_G) + \frac{K}{J_R}(\theta_G - \theta_R)$$

$$\ddot{\theta}_G = \frac{\tau_E}{J_R} + \frac{C}{J_G}(\dot{\theta}_G - \dot{\theta}_R) + \frac{K}{J_G}(\theta_R - \theta_G)$$

where θ_R, $\dot{\theta}_R$, and $\ddot{\theta}_R$ are the rotor position, velocity, and acceleration, respectively, in radians. θ_G, $\dot{\theta}_G$, and $\ddot{\theta}_G$ are the generator position, velocity, and acceleration, respectively, in radians and as sensed at the rotor side of the gearbox.

T_R is the rotor torque in ft.-lbs.
J_R is the rotor inertia in ft.-lbs. sec^2/rad
C is the damping factor in ft.-lb. sec/rad
K is the spring constant in ft.-lb./rad
τ_E is the equivalent electrical torque in ft.-lbs.
$P_e = \tau_e \times \dot{\theta}_G \times K_{eq}$ where τ_e is the electrical torque equivalent in ft.-lbs.
$\dot{\theta}_G$ is the generator speed in rpm
$K_{eq} = 0.142$ w/ft.-lb. rpm
and τ_e and $\dot{\theta}_G$ are expressed as sensed at the rotor side of the gearbox

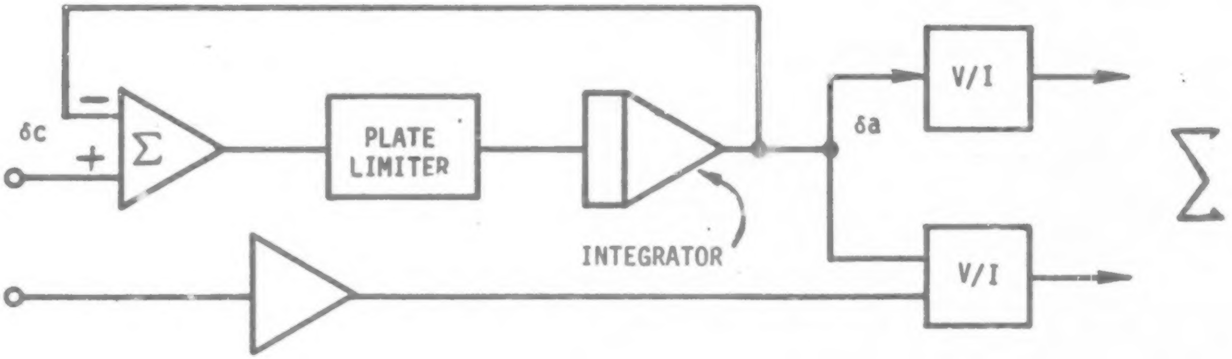
δc
+
−
Σ
PLATE LIMITER
INTEGRATOR
δa
V/I
V/I
Σ

Figure 9-30 Actuator Simulator Block Diagram

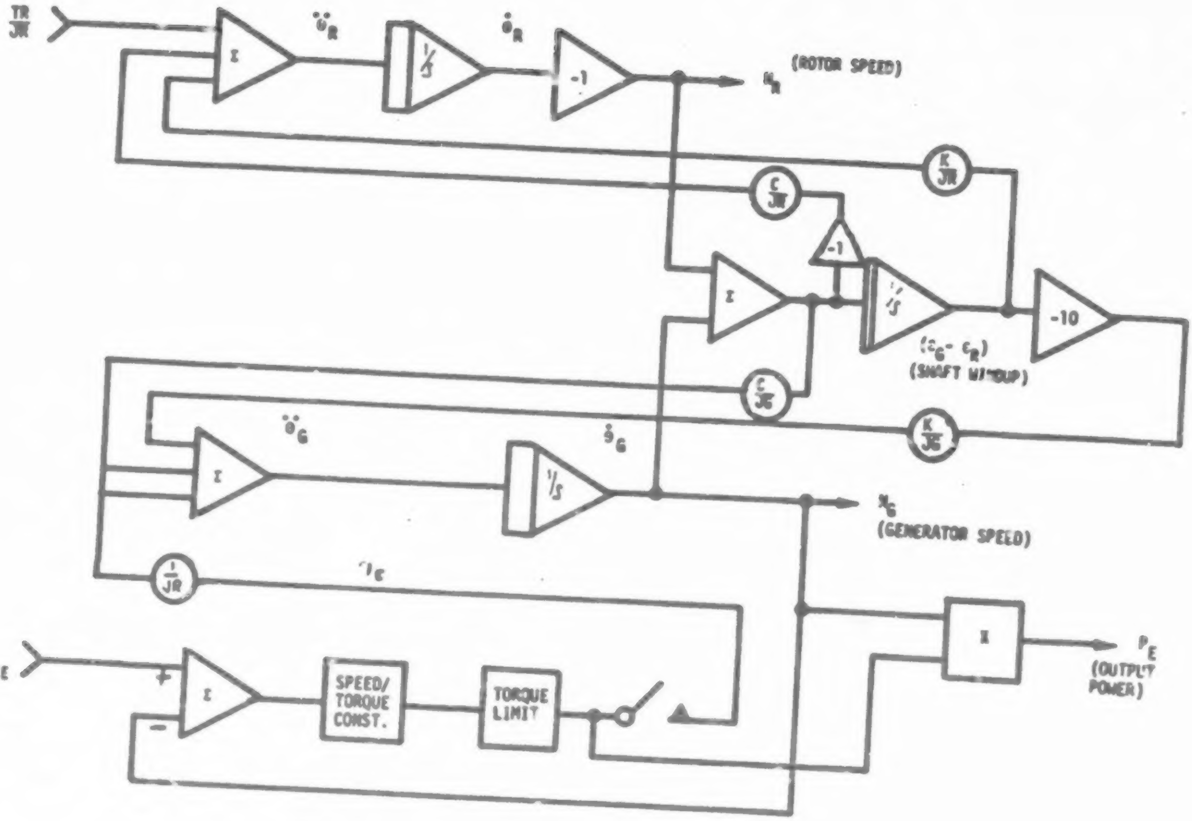
$\frac{TR}{JR}$
Σ
$\ddot{\theta}_R$
1/S
$\dot{\theta}_R$
-1
ω_R (ROTOR SPEED)
$\frac{K}{JR}$
$\frac{C}{JR}$
-1
Σ
1/S
-10
$(\varepsilon_G - \varepsilon_R)$
(SHAFT WINDUP)
$\frac{C}{JG}$
$\frac{K}{JG}$
$\ddot{\theta}_G$
Σ
1/S
$\dot{\theta}_G$
ω_G
(GENERATOR SPEED)
$\frac{1}{JR}$
T_G
GEN SPEED REFERENCE
+
−
Σ
SPEED/ TORQUE CONST.
TORQUE LIMIT
X
P_E
(OUTPUT POWER)

Figure 9-31 Dynamics Simulator Block Diagram

9.5.2 WIND TURBINE GENERATOR SIMULATOR SOFTWARE

The simulator's functions implemented in software are:

Digital Logic - The software simulates normal or abnormal sensor responses to commands from the controller, such as engage rotor brakes or turn on gearbox hydraulic system.

Yaw Logic - The software simulates the driving and resisting of yaw mechanisms including yaw error in degrees, gripper and brake sensors, and full stroke clockwise (CW) and counter clockwise (CCW) sensors.

Wind Simulation - The user can activate the simulation of a half-cosine wind speed gust and choose the values of the amplitude and period. Random variation of the magnitude and direction of the wind velocity may also be activated.

Control Data System - The simulator reads the control data system stream from the controller, and prints out values of control angle, power, rotor speed, wind speed, and yaw error.

Test Sequence - The simulator ramps the wind speed up or down and varies wind direction in a programmed sequence. Wind speed is programmed to increase from 0 mph to 45 mph, hold for 30 minutes, and the ramp down to 0 at 1 mph/min. The yaw error is programmed to vary between -25° and 25° at 1° min.

Keyboard Operations - While the simulator is running, messages and variables can be entered to:

- change the wind speed and yaw error
- change the magnitude of random variations of wind speed and direction
- change the state of any output sensor
- activate or deactivate a wind gust or test sequence
- force an abnormal response from any sensor

C-3

Aerodynamic Torque Calculation - The simulator calculates the rotor torque as a function of the rotor speed, wind velocity, and control angle. The equations for the torque calculations are:

$\tau = 2 C_q V_w^2 (29882.8)$

where τ = rotor torque in ft.-lbs.
V_w = wind speed in ft./sec
C_q = torque coefficient calculated as follows:
$C_q = A_0 + A_1\lambda + A_2\lambda^2$
$A_0 = C0 + C_1\delta + C_2\delta^2 + C_3\delta^3 + C_4\delta^4$
$A_1 = D0 + D_1\delta + D_2\delta^2 + D_3\delta^3 + D_4\delta^4$
$A_2 = E0 + E_1\delta + E_2\delta^2 + E_3\delta^3 + E_4\delta^4$
the constants C_i, D_i, E_i are obtained from fitting computed data to polynomial curve

Yaw - In response to the following yaw commands from the controller,

C6.1 Yaw hydraulic pump ON
C6.2 Yaw solenoid valve S1 (CW)
C6.3 Yaw solenoid valve S2 (CCW)
C6.4 Yaw solenoid valve S3 (gripper)
C6.5 Yaw solenoid valve S4 (holding brake)

The simulator activates the following signals:

S6.4 Yaw cylinder set #1 Full CW
S6.5 Yaw cylinder set #1 Full CCW
S6.6 Yaw cylinder set #2 Full CW
S6.7 Yaw cylinder set #2 Full CCW

Signals S6.4, S6.5, S6.7, S9.5, S9.7 respond to commands S6.1, C6.2, C6.3, C6.4 and C6.5 in a timed sequence as shown in Figures 9-32 and 9-33.

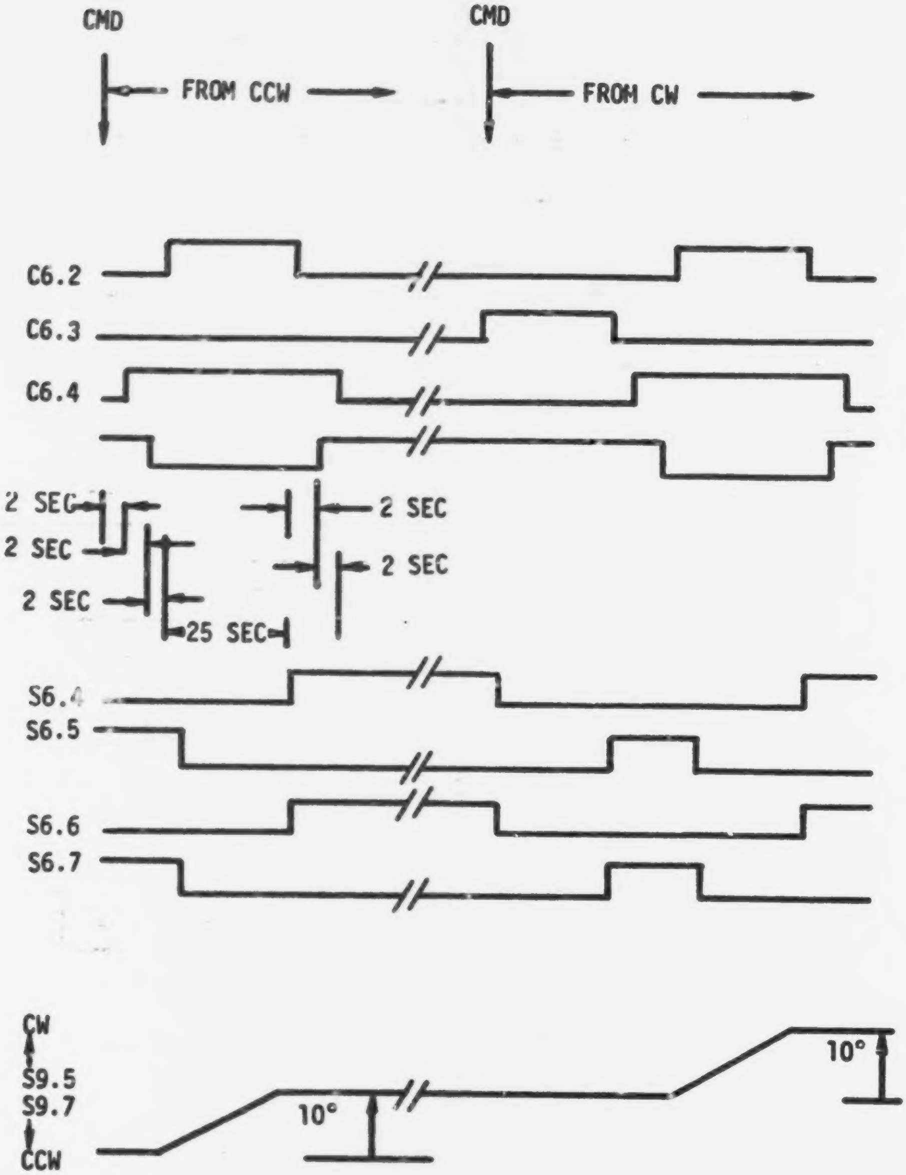
CMD
FROM CCW
CMD
FROM CW
C6.2
C6.3
C6.4
2 SEC
2 SEC
2 SEC
25 SEC
2 SEC
2 SEC
S6.4
S6.5
S6.6
S6.7
CW
S9.5
S9.7
CCW
10°
10°

Figure 9-32 Yaw Control Sequence - CW

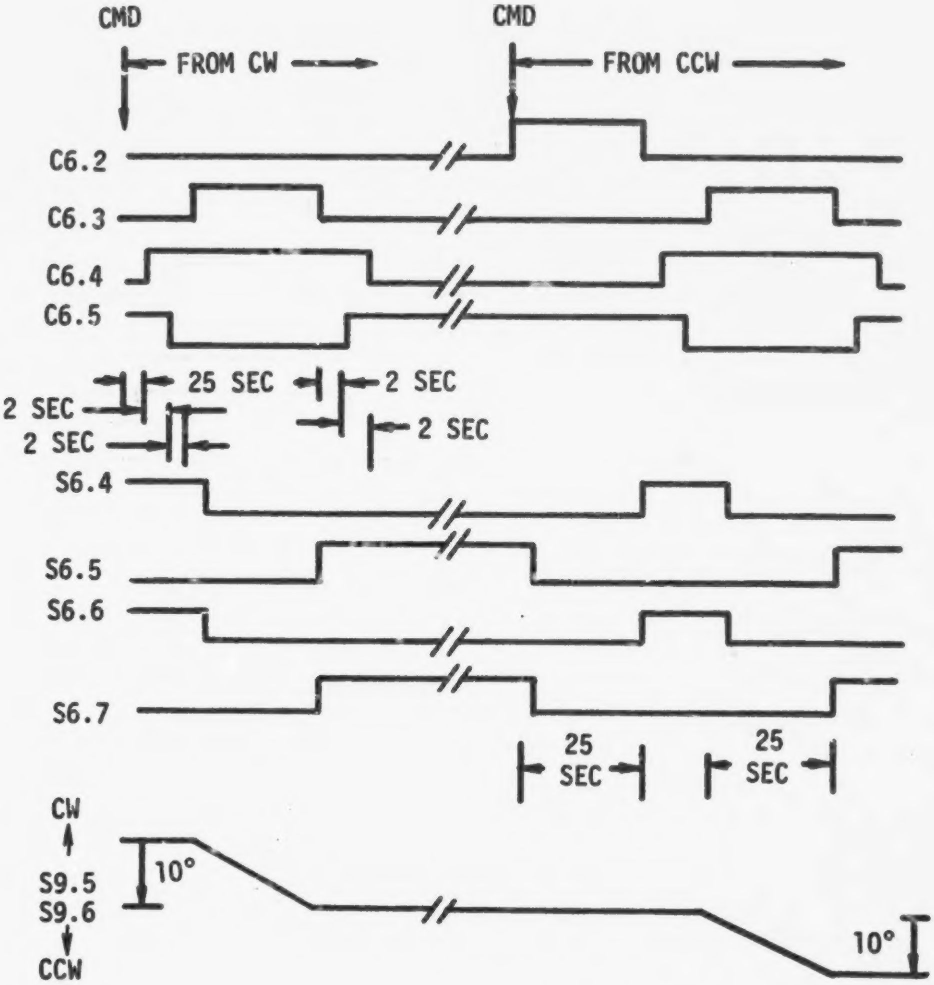
CMD
FROM CW
CMD
FROM CCW
C6.2
C6.3
C6.4
C6.5
2 SEC
25 SEC
2 SEC
2 SEC
2 SEC
S6.4
S6.5
S6.6
S6.7
25 SEC
25 SEC
CW
S9.5
S9.6
CCW
10°
10°

Figure 9-33 Yaw Control Sequence - CCW

9.6 DEVELOPMENT SYSTEM RESULTS

The software development system consists of the MOD-5A controller, a programming terminal, a wind turbine simulator, and an operator's terminal. Figure 9-34 is a block diagram of the development system. The primary purpose of the development system is to check the controller software under simulated operating conditions. The simulator provides inputs to the controller in response to the controller's output and the operator's commands. The controller software is exercised in a simulated environment that includes normal and abnormal conditions.

The automatic sequence, including start-up, ramp/sync, and power generate, was recorded on strip charts, shown in Figure 9-35. Yaw error correction and the transition from electrical to aerodynamic torque control are shown in Figure 9-36. Figure 9-37 shows yaw correction from a large initial error. The printout from the operator's terminal is shown in Figure 9-6.

The goals for memory and execution cycle time were achieved in the final program. The design goal for cycle time is 100 msec; the worst case operating time is 89 msec and 83 msec normally. Table 9-20 lists the execution times for individual software moduli. The goals for user memory were 40K total, a 20K PROM and a 20K RAM. The final program has 17.7K of PROM and 17.3K of RAM. Table 9-21 lists the memory used for the individual moduli of the final program.

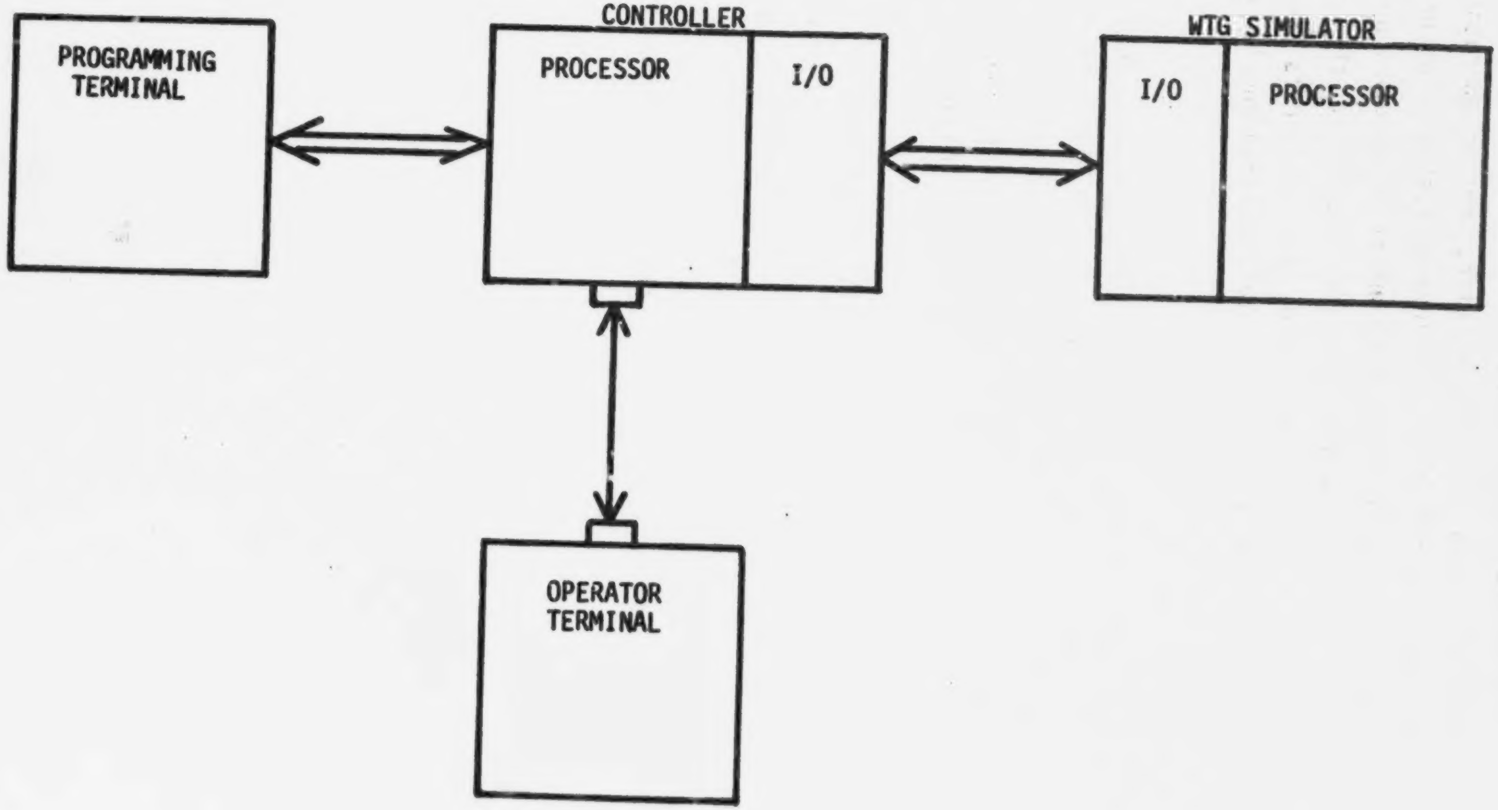
CONTROLLER
PROGRAMMING TERMINAL
PROCESSOR
I/O
WTG SIMULATOR
I/O
PROCESSOR
OPERATOR TERMINAL

Figure 9-34 Software Development System Block Diagram

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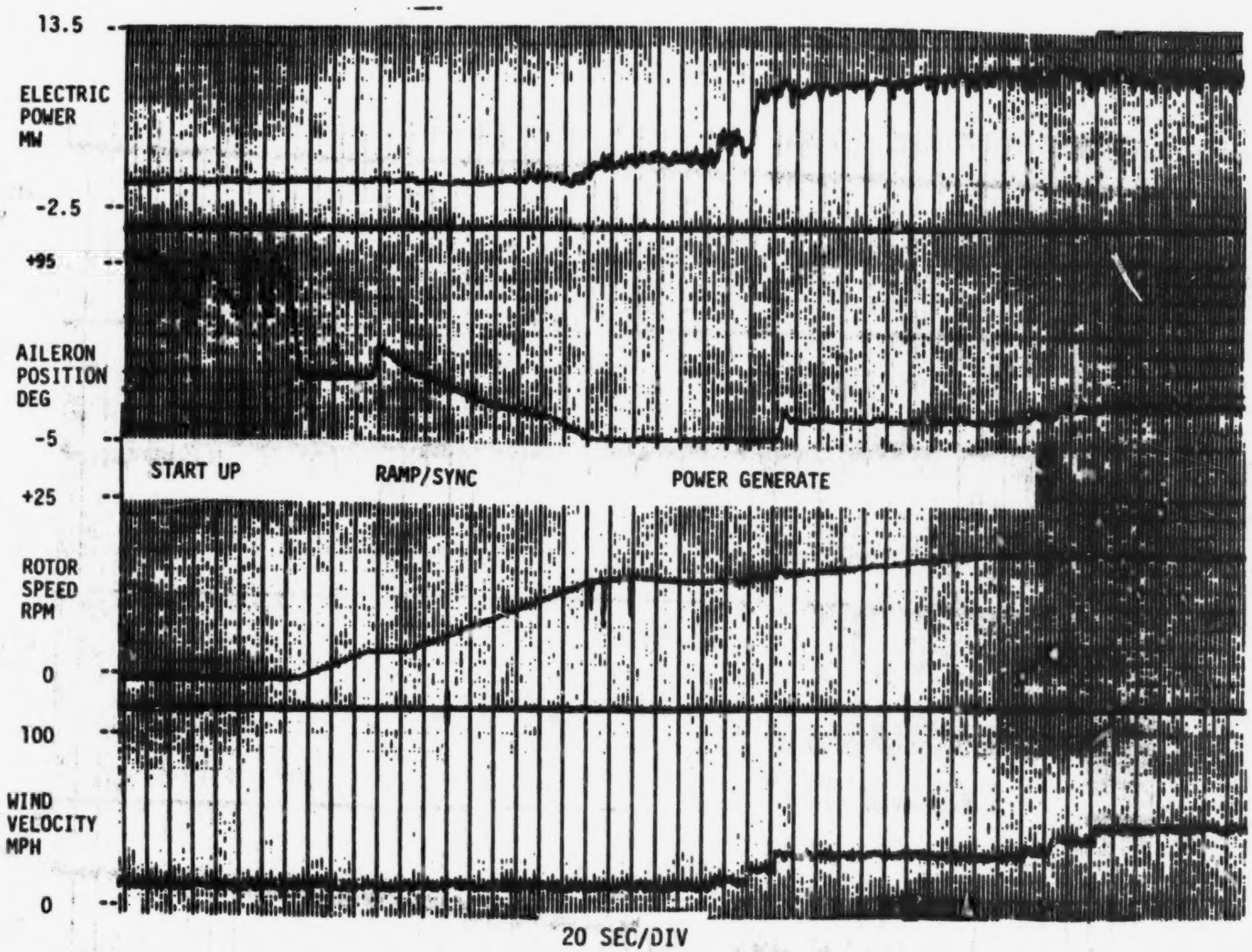

Figure 9-35 Automatic Sequence

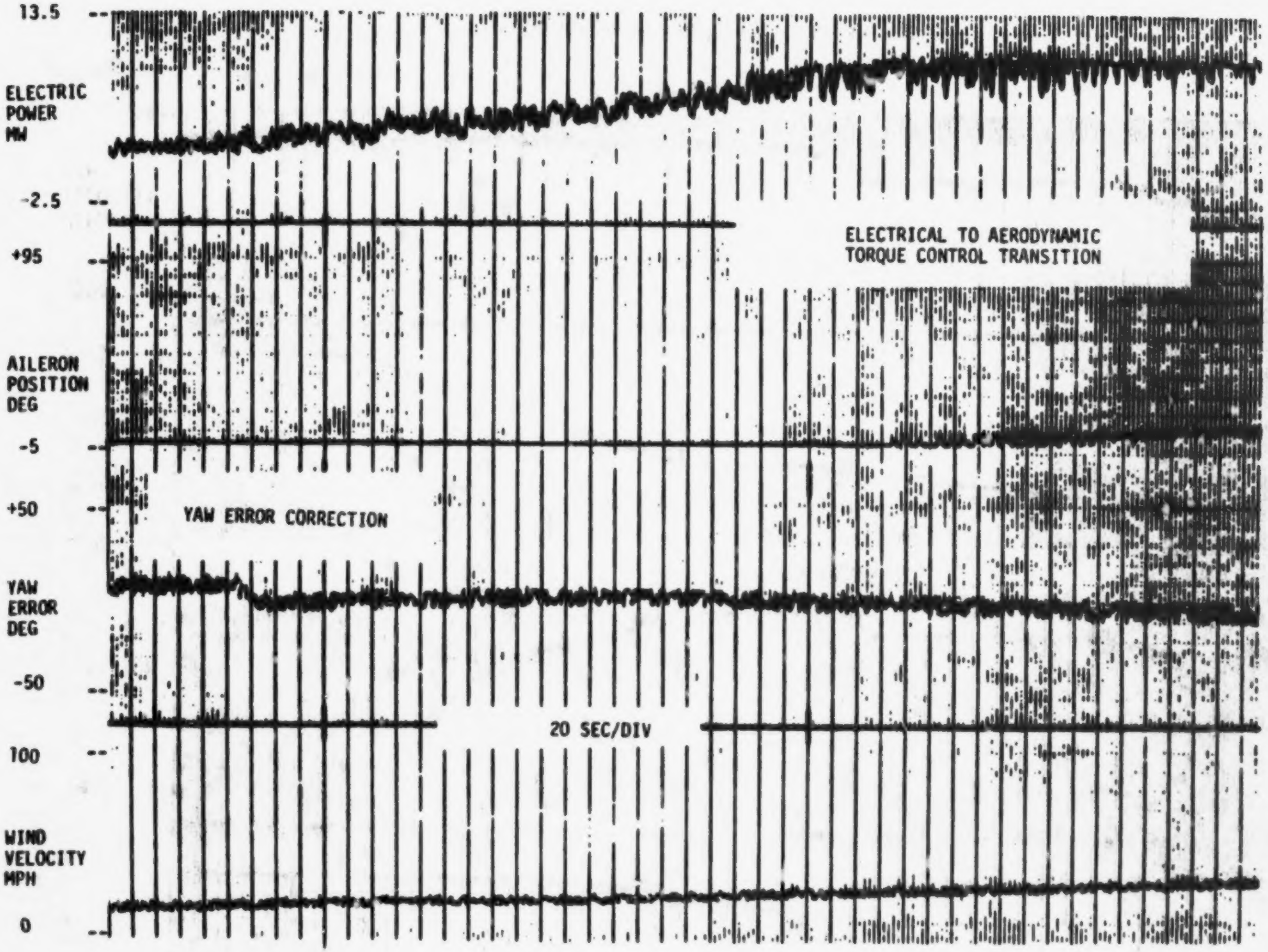

Figure 9-36 Yaw Error Correction and Torque Control Transition

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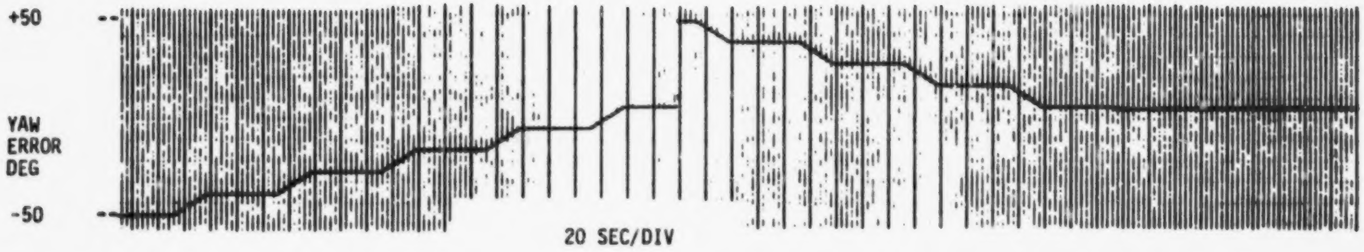

Figure 9-37 Yaw Correction from Large Error

Table 9-20

Timing of Controller Software Modulus

MODULE	EXECUTION TIME (LONGEST SEGMENT) (MSEC)
EXEC	.54
ISM	9.66
DATA PROCESSING	14.26 → 15.46
MODE	6.56
OSM	2.96
RMP	.12
NSD/ESD	.26 → 6.16
ALARM	30.46
YAW	.86
RAMP/SYNC	.26
START-UP	.21
CDS	.21 → 10.26
DATA COMMUNICATION (SITE/REMOTE)	.4 → 1.96
POWER GEN	6.06
DATA ARCHIVING	.26 → 2.76

NORMAL OPERATION: EXEC, ISM, DATA PROCESSING, MODE, OSM, ALARM, CDS, DATA COMMUNICATIONS (SITE & REMOTE)/R, DATA ARCHIVE = 81.62 MSEC.

N.O. ± YAW & RMP: 82.6 MSEC.

N.O. ± WORST CASE OPERATION (NSD/ESD): 82.6 + 6.16 = 88.76 MSEC

Table 9-21

Memory Usage

PROGRAM (PROM)

MODULE	# BYTES
EXEC & INIT	1977
MODE	3457
DATA PROCESSING	877
ISM/OSM	471
START-UP	765
RAMP/SYNC	948
POWER GEN.	310
NSD/ESD	463
AILERON CONTROL	399
YAW	379
ROTOR HYDRAULICS	38
ALARM	304
DCSO/DCRO	1387
DCSI	1155
CDS	419
MANUAL	2278
DATA ARCHIVE	384
REAL TIME CLOCK	147
FDX COMM.	1011
PK COMM.	969
	18138 (17.7K)

RAM:	# BYTES	# K
DEVELOPMENT SYSTEM	3315	3.3*
FINAL SYSTEM	17715	17.3

*REDUCED RAM CAPACITY FOR DATA ARCHIVE USED FOR DEVELOPMENT

Volume III
Book 2

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10.0 MANUFACTURING

10.0 MANUFACTURING

10.1 MANUFACTURING REPORT

The objective of the manufacturing section is to describe GE's plan for the manufacture and assembly of the prototype MOD-5A wind turbine generator. An illustrated overview of the manufacturing and assembly flow is shown in Figure 10-1, showing the major components, subassemblies and manufacturing events, from the initial fabrication through the site erection.

The work shown in this plan has three steps; fabrication, factory integration and assembly, and site assembly. Throughout this report, the manufacturing description emphasizes conventional methods for performing these steps. Suppliers for specialty articles, such as the gearbox, are identified. Erection and assembly techniques are conventional and are based on experience. The result is a manufacturing plan based on conventional practices, which minimizes the potential for manufacturing defects caused by immature techniques and processes and which ensures that the manufacturing costs are soundly based. This philosophy could not be applied to the fabrication of the laminated wood and epoxy blade structure. For the blades, some developmental processes, such as field joint assembly, are required. These developmental processes are discussed in 10.5.5, the blade fabrication section, and 10.7.1, the blade field assembly section.

10.2 MAKE/BUY

Evaluations of GE's capability to make components was performed during the design of the wind turbine generator. Two criteria were required for a decision to make any component, 1) the technology and manufacturing capability for designing and producing the component existed in a department of GE and 2) the component could be produced at a competitive cost. Examples of such components are the generator, switchgear, and transformers. If these criteria were not satisfied, components were to be procured.

10.3 PROCUREMENT ACTIVITY

The make/buy evaluation for the MOD-5A prototype indicated that only three major components out of 26 would be provided by GE. Therefore, the prototype component acquisition would be primarily a procurement effort.

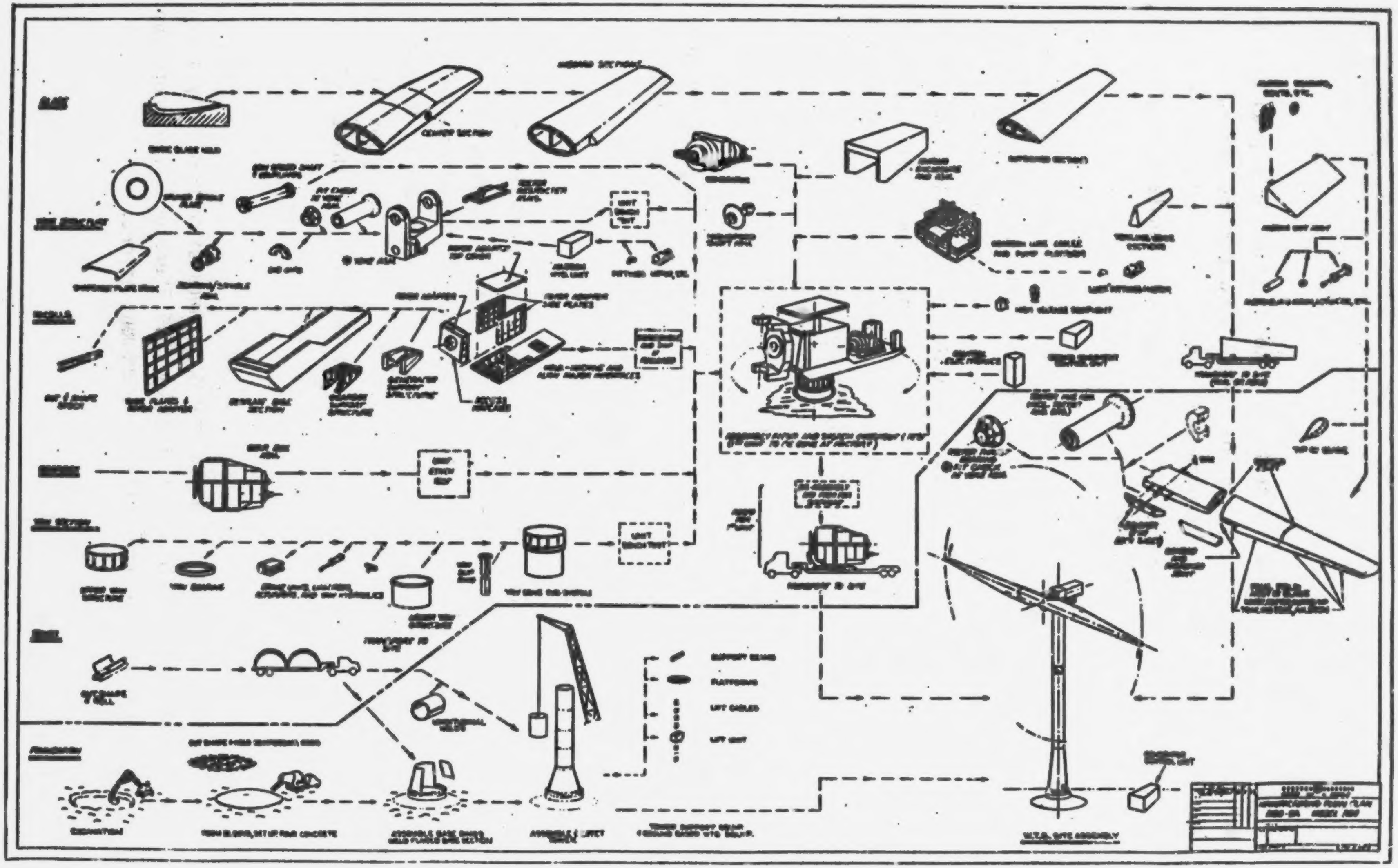
CENTER SECTION
UNIT BENCH TEST
OUTBOARD SECTION
HIGH VOLTAGE EQUIPMENT
TRANSPORT TO SITE
SUPPORT BEAMS
PLATFORMS
LIFT CABLES
LIFT UNIT
EXCAVATION
W.T.G. SITE ASSEMBLY
MOD-5A MODEL 304

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Figure 10-1 Manufacturing Flow Plan MOD-5A Model 304

Considerable effort was expended during the design phase to identify qualified sources and initiate working relationships with these suppliers, to provide the information required to produce designs and specifications and establish cost budgets.

The objectives of the procurement effort of this program are listed below:

- obtain standard hardware design data and prices
- determine feasibility and cost-effectiveness of using "modified" standard hardware, such as bearings
- develop specifications for special components, such as the generator
- obtain cost estimates for cost of energy evaluations
- determine supplier's manufacturing methods and processes, to insure cost-effectiveness of design
- develop qualified bidders lists, from evaluating suppliers capabilities
- produce designs of special components, such as the gearbox and laminated wood blades
- prepare bid packages for all hardware to be procured
- obtain firm quotes and proposals suitable for source selection

The following section discusses these efforts in three categories; major subcontracts, major purchases and general purchases.

10.3.1 MAJOR SUBCONTRACTS

Major subcontracts are defined as high-cost or high risk procurements that required a significant design and development effort. The major subcontracts were for the wooden blade, gearbox, tower and foundation, generator, ailerons, and transportation.

10.3.1.1 Wooden Blade

The blade subcontractor was selected as a result of the conceptual design trade-off study that selected the laminated wood blade material. Gougeon Brothers, Inc. (GBI) was selected because their design had the lowest cost of energy in a production scenario. The subcontract included five activities.

- Design - GE retained the design responsibility, and GBI acted as a consultant and manufacturing expert. GBI was also responsible for producing the fabrication drawings and manufacturing and quality control plans.

- Material Development - The design allowables for laminated wood had to be defined by tests. GBI fabricated all the test articles, acted as a consultant for the development of the configuration and requirements for the tests, and participated in the evaluation of the results.

- Process Development - The fabrication process was based on GBI's existing technology. The technology had to be expanded and verified before the blade fabrication was committed. Two blade sections, a finger joint unit and center blade unit, were planned to demonstrate the acceptability of the fabrication process selected. Both blade sections were to be full scale. Only the finger joint unit was fabricated.

- Molds - GBI was responsible for designing and fabricating the molds and assembly fixtures required for the fabrication process.

- Fabrication and Assembly - GBI was responsible for fabricating the blade sections, and supplying supervision and other special skills required to assemble the blade in the field.

10.3.1.2 Gearbox

The gearbox subcontractor was selected after a multi-staged competition. Philadelphia Gear Corporation (PGC) won this competition because of their technical approach and low cost. The subcontract comprised two activities:

- Design - PGC performed the initial configuration trade-off studies and supported GE during the selection of the final design. PGC designed the gearbox, with scheduled design reviews by GE, NASA, and contracted consultants.

- Fabrication - PGC was responsible for fabricating and testing the gearbox. The accepted product would be shipped to GE's factory assembly site for assembly and testing.

10.3.1.3 Tower and Foundation

The tower and foundation subcontractor, Chicago Bridge and Iron (CBI), was selected during the proposal cycle because of their previous water tower experience and capability, and they entered into a teaming agreement with GE. The resulting subcontract comprised two activities:

- Design - CBI performed the initial configuration trade-off studies and supported GE during the final selection of configuration. CBI designed the tower and foundation, with scheduled design reviews by GE, NASA, and contracted consultants.

- Fabrication - CBI was responsible for foundation construction, tower fabrication and erection.

10.3.1.4 Generator

Data for the selection of a generator subcontractor was accumulated during a series of competitions that started during the conceptual design. The subcontract for this activity would have required:

- Design - The subcontractor was responsible for the design, with scheduled design reviews.
- Fabrication - The subcontractor was responsible for fabricating and testing the generator subsystem. The accepted generator would be shipped to GE's factory assembly site for assembly and testing.

10.3.1.5 Aileron

A subcontractor would have been selected to handle two activities:

- Design - The subcontractor was responsible for the design, with scheduled design reviews.
- Fabrication - The subcontractor was responsible for fabricating and testing the individual ailerons. The ailerons would be assembled to the blade and tested as a part of GE's blade assembly.

10.3.1.6 Transportation

The transportation subcontract was for the transportation of all wind turbine components except tower fabrications from a west coast depot to the site in Hawaii. A competitive transportation subcontract was planned.

10.3.2 MAJOR PURCHASES

Major purchases were defined as high-cost procurements. The major purchases were to have been made on a competitive basis. Major structures and large bearings are examples of major purchases.

10.3.3 GENERAL PURCHASES

Other procurements were defined as standard hardware, whether the hardware would be modified or used intact. These items were to have been procured on a competitive basis.

10.4 MAKE PLAN

Major components such as the generator, transformers and switch gear would be supplied from departments in GE. In addition, some small components would be fabricated in GE's shops. Electrical components, such as the system display module, signal conditioning and emergency shutdown components would also be produced by GE.

10.5 MATERIAL FLOW AND ASSEMBLY PLAN

A sequence of manufacturing operations was determined as part of the manufacturing planning activity. Manufacturing cost estimates were generated for fabricated parts, to provide a benchmark for vendor's quotations, identify producibility improvements for design feedback, highlight areas of high cost, and provide costs if vendor's quotes were not available.

Manufacturing cost estimate data is summarized in each of the following sections. The data includes the drawing number, title, material types, weights, and material cost and labor estimates.

The material weight shown is the estimated machined weight of the structure, plus a 15% allowance for waste and drop-off. The material cost was determined by multiplying the material weight by a cost per pound factor. The direct labor hours are an estimate of the effort required for fabrication or assembly. The indirect labor hours are an estimate of the support effort required to accumulate, move, store, and position raw material and finished components. The set-up hours represent the time required to accumulate tools, fixtures, shop supplies and to prepare an arrangement that will facilitate manufacturing. Sections 10.5.1 through 10.5.3 contain the manufacturing cost estimate forms for the yaw, nacelle, and yoke assemblies.

10.5.1 YAW FABRICATION

The yaw subsystem fabrications will be made by manufacturing methods that are well within the current state of the art, and that are standard industry practices.

The manufacturing cost estimates for the upper and lower yaw structure describe detailed part fabrications. This structure consists of a rolled and seam welded cylinder, bearing interface welded ring, fabricated gussets and gusset channel subassemblies. The complete lower yaw structure is fitted, welded together, inspected and finally machined. Other hardware, such as the yaw support brackets, platform floor, and support beams are also required for the assembly.

The yaw fabrication plan describes a conventional approach towards estimating the cost of the accumulation, preparation, welding and machining of the yaw structures. Table 10-1 is a summary of manufacturing cost estimate data.

Figure 10-2 is a manufacturing cost estimate sheet, describing the process plan for the upper and lower yaw structures, with the exception of the yaw bearing, which was a major purchase. The material code, weight, cost, operations, tooling and estimated labor hours required to produce each component was documented.

10.5.2 NACELLE FABRICATION

The nacelle subsystem fabrication consists of the bedplate, rotor and generator adapters, side supports and top covers. The components are aligned and bolted together.

The nacelle bedplate structure supports the rotor assembly through the gearbox structure, generator structure, electrical control cabinet, lube service module and fairing. The bedplate structure interfaces with the upper yaw structure.

The bedplate structure is 532 in. long, 164 in. wide and 66 in. high. When the gearbox mounting structure is installed on top of the bedplate, the combined height is 96. in.

The bedplate structure is a conventional structural steel weldment, made up of A572 steel. The elements are prepared by shearing to size, cut with a saw and oxy-burning to shape. The edges of parts to be welded are prepared as required. Subassemblies are first inspected, fitted, then welded. These assemblies are fitted and welded into the bedplate assembly.

The entire bedplate structure, after inspection, is stress-relieved in a large furnace. Scale generated by this furnace treatment is removed by shotblasting. At this time welds may be inspected in ultrasonic or radiographic

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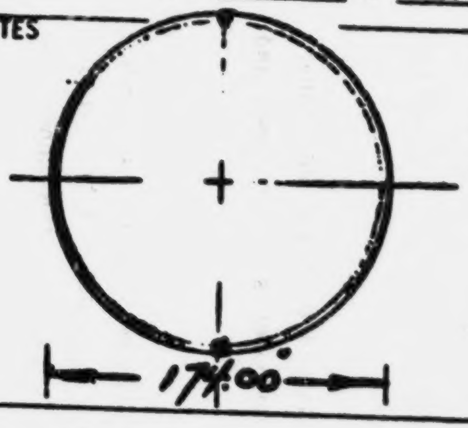
EST.
SHEET ______ OF ______ DATE ______

DWG/SK NO.
47E382219
PROJ
MOD-5A-WTG
TITLE
LOWER YAW HOUSING CYLINDER
MATL A678 GRADE B
SIZE 75 x 72 x 275" x (2)

UNIT (1B/FT^2/FT/IN. ETC.) 8316 LBS
MATL UNIT COST ______ $/ LB

MAT COST ______

NOTES



OPN NO	OPERATION DESCRIPTION	SET UP HR	TOOL DESC	TOOL EST $	EQUIP MACH	EQUIP EST $	LABOR HOURS DIRECT	LABOR HOURS IND.	MISC. EXPENSE
10	SHOTBLAST (2) PLATES	0.5					2.0	2.0	
20	LAYOUT WIDTH & DEV. LENGTH	0.5					2.0		
30	OX-BURN WIDTH & LENGTH	0.5					2.0	1.0	
40	WELD PREP (3) EDGES	0.5					4.0	0.5	
50	ROLL (2) 180° CYLINDER SEGMENTS	1.0	SWEEP TEMP				4.0	1.0	
60	FIT-UP CYLINDER (ADD INTERNAL TEMPORARY STIFFNERS)	1.0	SPIDER FIX				4.0	1.0	
70	SUBMERSIBLE ARC-WELD (2) SEAMS	1.0					1.0	0.5	
80	GRIND WELDS SMOOTH (INTERNAL & EXTERNAL)	0.5					1.0		
90	INSPECTION (VISUAL)						0.5	0.5	
100	INSPECTION (MAGNETIC PARTICLE)	0.5					1.0		
110	INSPECTION (ULTRASONIC AND OR RADIOGRAPHIC)	1.0					2.0		
120	GRIND DEFECTIVE WELD	0.5					1.0	0.5	
130	REPAIR WELD AND GRIND SMOOTH	0.5					1.0	0.5	
140	INSPECT WELD REPAIR	1.0					0.5	0.5	
150	FACE ONE END OF CYLINDER	4.0					2.0	1.0	

Figure 10-2 Typical Manufacturing Cost Estimate Sheet

Table 10-1. Yaw Subsystem Fabrication Summary

Item	Material	Material Weight (lbs.)	Material Unit Cost ($/lb.)	Material Cost $	Labor Hours			Tool Cost $	Misc. $
					Set-up	Direct	Indirect		
Lower Yaw Housing	A678 B	8,316	.6	4,990	13	32	9	800	---
Lower Yaw Bearing Interface Ring	A678 B	16,665	.6	10,000	15	33	8.5	---	---
Lower Yaw Housing Gusset	A678 B	1,928 (36 total)	.6	1,160	2	9.5 (per gusset)	3.0	600	---
Lower Yaw Housing Channel	A678 B	84 (12 total)	.6	50	1	9.5 (per channel)	2.0	500	---
Lower Yaw Structure Assembly	---	---	--	---	53	312	155	2,400	1,500
Upper Yaw Structure Fabrication	A572 (50)	25,300	.6	15,180	46	612	233	11,500	2,000

tests. Defective welds are ground, repaired, and blended. Finally the entire structure is finished with prime paint.

The bedplate is machined and drilled for the principal interfacing components. The upper yaw flange area is face-milled on the bottom side, and bolt holes are drilled and reamed to size. The part is turned over and the gearbox mounting rails, rotor adapter, generator support areas are all face milled in relation to the yaw flange surface. Mounting holes are drilled and reamed to satisfy the drawing specifications.

The machined surfaces are shotblasted and prime painted, then the gearbox and generator mounting structures are bolted in place. Tapered locating pins are placed in both structures. The 7° inclined plane is milled on gearbox and generator mounting structures, and mounting holes are drilled and reamed in both surfaces. Finally, the machined areas are shot blasted and primed.

The rest of the nacelle components, consisting of the rotor adapter structure, rotor adapter side supports, top structure forward section, top structure aft section, and top structure cross-section are all conventional fabricated structures. They are cut to size, prepared for welding and fitting, welded, stress relieved, shot blasted, paint finished, machined, drilled and reamed, and final paint finished, in that order.

A manufacturing cost estimate summary is listed in Table 10-2 for each of the nacelle fabrications.

10.5.3 YOKE FABRICATION

The yoke weldment is constructed in the same manner as the other structural components, such as the bedplate and nacelle. With the exception of the yoke center hub, which is a machined forging, the pieces are sheared, cut with a saw, or oxy-burned to shape, the weld surfaces are prepared, fitted, jigged, and welded. The assembly is stress relieved, shotblasted, and welds are inspected and repaired, then the structure is prime painted. The two bearing caps are also prepared in this way, then machined and fitted to the yoke sockets.

Table 10-2 Nacelle Subsystem Fabrication Summary

Item	Material	Material Weight (lbs.)	Material Unit Cost ($/lb.)	Material Cost $	Labor Hours Set-up	Labor Hours Direct	Labor Hours Indirect	Tool Cost $	Misc. $
Bedplate Structure Weldment	A572 (50)	108,000	.6	64,800	71	604	456	---	7,000
Bedplate Machining/Drilling	---	---	--	---	39	381	32	5,000	---
Rotor Adapter Structure Weldment	A572 (50)	65,300	.6	39,200	54	414	342	---	4,200
Rotor Adapter Structure Machining/Drilling	---	---	--	---	18	126	28	9,000	---
Rotor Adapter Side Support Weldment	A572 (50)	23,500	.6	14,100	13	108	92	---	1,500
Rotor Adapter Side Support Machining/Drilling	---	---	--	---	8	54	14	---	---
Top Structure - Forward	A572 (50)	16,900	.6	10,140	10.5	97	89	---	1,200
Top Structure - Forward-Machining/Drilling	---	---	--	---	2.5	26	9	1,500	---
Top Structure-Aft	A572 (50)	4,300	.6	2,580	10.5	55	50	---	---
Top Structure-Aft-Machining/Drilling	---	---	--	---	2.5	15	8	600	---
Top Structure-Cross	A572 (50)	1,000	.6	600	9.0	35	26	---	300

The yoke is assembled by aligning and bolting together two yoke bearing cap weldments and boring the inside diameter for the teeter bearing hardware installation. Next, the inside diameter of the yoke center hub is machined to accept the forward and aft rotor bearings. Then the torque plate is aligned and clamped to the yoke center hub face. The existing torque plate holes are used as guides and bolt holes are drilled and reamed through the yoke center hub face flange. Both rotor bearings are installed in the yoke, and the yoke is assembled on the rotor support spindle. The low speed shaft and couplings are positioned inside the rotor support spindle and the forward coupling's external splines are engaged with the torque plate's internal splines. A special fixture is temporarily attached between the spindle and the shaft to support the low speed shaft, until the aft coupling is connected to the gearbox splines, which is done in the field.

Table 10-3 is a manufacturing cost estimate summary for the yoke weldment.

10.5.3.1 Fabrication of Low Speed Shaft and Couplings

The low speed shaft is approximately 180 in. long and 35.5 in. in diameter. It weighs 44,000 lbs. after machining. The first operation is to bore a hole 10 in. in diameter down the center. Each end is faced and chamfered. Approximately 2.5 ft. at each end is ground to a specified taper. The center section is machined to diameter, then each end receives eight tapped holes. The tapered ground surfaces are sprayed with a protective coating and the center section is prime painted.

The coupling hubs, fore and aft, are each machined in a similar fashion. These parts are about 5 ft. in diameter by 2.5 ft. long. One end is faced, the outside diameter is turned, the opposite end is faced to length, and chamfered. The inside is rough-bored, then taper-ground to match the shaft. The external spline teeth are cut, then nitrided, and scale is removed. The part is washed, inspected, and coated with primer paint or protective coatings.

Table 10-4 is a manufacturing cost estimate summary for the shaft and hubs.

Table 10-3. Yoke Weldment Summary

Item	Material	Material Weight (lbs.)	Material Unit Cost ($/lb.)	Material Cost $	Labor Hours Set-up	Labor Hours Direct	Labor Hours Indirect	Tool Cost $	Misc. $
Yoke Center Hub Forging	508 (22)	84,000	.6	50,400	39	216	164	---	17,000
Yoke Weldment	633 (C)	127,000	.6	76,200	187	3,096	1,580	---	27,500
Bearing Cap Weldment	633 (C)	12,700	.6	7,620	14	122	70	---	1,000
Yoke Machining Assembly	---	---	--	---	95	36	88	---	---

Table 10-4. Low Speed Shaft Components Summary

Item	Material	Material Weight (lbs.)	Material Unit Cost ($/lb.)	Material Cost $	Labor Hours			Tool Cost $	Misc. $
					Set-up	Direct	Indirect		
Low Speed Shaft	A502 (4B)	52,000	.6	31,200	22	132	28	500	---
Aft Coupling Hub	2.5% Nitriding Steel	21,000	.6	12,600	19	204	24	10,000	1,500
Forward Coupling Hub	2.5% Nitriding Steel	24,000	.6	14,400	19	204	24	---	1,500

10.5.3.2 Fabrication of Torque Plate

The torque plate is 127 in. in diameter and is 1 ft. thick. Its raw weight is 75,000 lbs. The part is fabricated in one piece because of its critical function in transmitting blade power.

The rough diameters are oxy-burned to shape. One side is faced and beveled, and the internal shoulder is turned. Twenty-four holes are drilled and tapped.

The part is inverted, faced and bevel turned on the second side, and the inner diameter is bored. Twenty-four holes are drilled and tapped. The internal spline teeth are cut to match the forward hub. The remaining 122 holes are drilled and reamed.

The internal teeth are nitride hardened, scale is removed, and the part is prime painted and coated as required.

Table 10-5 is a manufacturing cost estimate.

10.5.3.3 Teeter Hardware Fabrication

The teeter hardware consists of a teeter shaft, two teeter bearing assemblies, two bolster inserts, and four teeter restrictor brake assemblies.

After it is machined and the bearing fit is checked, the teeter shaft is sent to the blade manufacturer. The center teeter shaft is wrapped with glass fiber and bonded. The center blade fitting is checked, then the shaft is packaged for shipment to the field site, where the teeter shaft will be permanently bonded to the blade.

There are two bolster inserts. After they are machined and the fitting is checked, the inserts are sent to the field site.

The teeter restrictor brake housing fabrication consists of a left and right housing wall and coverplate. There are four units bolted on the yoke and pinned to the blade and bolster assembly.

Table 10-6 is a manufacturing cost estimate.

Table 10-5. Torque Plate Summary

Item	Material	Material Weight (lbs.)	Material Unit Cost ($/lb.)	Material Cost $	Labor Hours			Tool Cost $	Misc. $
					Set-up	Direct	Indirect		
Torque Plate	AISI 4340	75,000	.6	45,000	25	314	26	1,600	1,500

Table 10-6. Teeter Hardware Summary

Item	Material	Material Weight (lbs.)	Material Unit Cost ($/lb.)	Material Cost $	Labor Hours			Tool Cost $	Misc. $
					Set-up	Direct	Indirect		
Teeter Shaft	AISI 1026 Hot Finished Tube	6,500	.6	3,900	8	31	24.5	---	---
Bolster Insert	A508 (4B)	11,631	.6	6,979	9	84	15	---	---
Teeter Restrictor Housing	----	1,425/each (4 total)	.6	3,420 (4)	13	149	53	1,500	1,000

10.5.4 TOWER FABRICATION

The towers will be fabricated at CBI's manufacturing plants. CBI is equipped for the fabricating, welding, machining, and painting operations required to produce wind turbine towers. The production of this tower is similar to the production of single pedestal waterspheres, which is one of CBI's product lines.

10.5.4.1 Fabrication of Parts

Raw material is sent into the fabricating shop as it is ordered for the first operation. In the case of cone and shell plates, the first operation is the computer numerically-controlled burner. The burner cuts and bevels the edges of the plates, to prepare them for welding. After the pieces are inspected for required dimensions, the plates are bent to the proper curvature by the plate bending roll. Smaller parts, such as bell door components, base plates, anchor chairs, ladders, platforms, and flanges, are processed simultaneously with the fabrication of the larger plates, such as cone and shell plates. The plant production schedule for the tower components brings all of these parts together in the weld shop for fitting and welding the components.

10.5.4.2 Assembly and Welding

Fabricated parts are routed to the predetermined fitting and welding area, which is equipped with the jigs and fixtures that are necessary to accurately locate pieces in relation to one another and to restrain those pieces during the automatic welding operation. A non-destructive examination is performed, as required by the drawings, and any repairs indicated by the examination will be made.

10.5.4.3 Blasting and Painting

Components are sent to the blasting area from the fabrication and welding shops. In the proper sequence, the components are carried through the automatic blasting cabinet where rust and scale are removed from the steel and the proper surface profile is attained for the primer paint. As the parts travel out of the blasting booth, the edges are masked. The parts travel into the automatic painting booth for the application of primer paint. The painting is inspected immediately, before the pieces are moved to the paint drying area. Components are stored in the drying area while the primer paint is cured.

10.5.4.4 Loading and Shipping

The loading yard crew selects the components to be loaded on railroad cars from the paint area. A typical load would be a mixture of bell plates, and a variety of smaller components, such as bell doors, base plates, anchor chairs, ladders and platforms. Another typical load would comprise several cylindrical shell plates and a variety of small parts. After all parts are loaded on the railroad car, the yard crew would protect and secure the components. Each day, the CBI traffic department would arrange for the railroad company to send loaded railroad cars to the construction site.

10.5.4.5 Standardization

CBI's experience with their product lines shows that high labor components that are used repetitively are produced most economically in a well-engineered, specially equipped facility. This concept can be applied to the bell plates, bell doors, bell to cylinder transition knuckles, and ladders.

A component production facility for each of these items will be set up at one of CBI's plants. The plant will be selected based on its experience with similar components, cost of fabrication and transportation.

10.5.4.6 Detailed Manufacturing Sequence

Typical operation sequences are listed:

A. TOWER BASE PLATES

1. Receive and inspect plates, identify material and collect dimension data
2. Store materials in the open yard
3. Move material to the fabrication shop
4. Shape burn the plates on the computer numerically controlled burning machine
5. Inspect the quality of dimensions and edges
6. Drill holes on computer numerically controlled machines
7. Inspect hole size and location
8. Move material to the weld shop

B. TOWER CONE (BELL) PLATES

1. Receive and inspect plates
    a. Identify Material
    b. Collect dimension data
2. Store material in the open yard
3. Move material to the fabrication shop
4. Shape burn and bevel on the computer numerically controlled burning machine
5. Inspect the quality of dimensions and edges
6. Move material to the forming machine
7. Form curvature on plate bending roll
8. Inspect for uniform curvature
9. Move material to the weld shop
10. Fit and tack base plates and anchor bolt chairs to coneplates
11. Automatically weld parts to cone plates.
12. Clean the welds
13. Inspect, examine and repair welds
14. Move material to the paint shop
15. Auto blast and paint
16. Store during paint curing
17. Load material on rail cars
18. Ship to site

C. TOWER CONE (BELL) DOOR

The cone plate comes from step 9 of Tower Cone Plates, and the detailed parts come from the detail shop.

1. Lay out and burn door opening in cone plate
2. Inspect the location and edge quality
3. Move the cone plate to the welding fixture
4. Fit and tack door framing angles to the inside of the cone plate
5. Fit and tack door jamb plates into the opening
6. Inspect the fitting
7. Automatically weld all parts to the cone plate
8. Clean the welds
9. Inspect, examine and repair welds

10. Assemble the door to the jamb
11. Move the cone plate to the paint shop
12. Blast and paint
13. Store during paint curing
14. Load on rail cars
15. Ship to site

D. TOWER TRANSITION KNUCKLE

1. Receive and inspect plates, identify materials and collect dimension data
2. Store materials in the open yard
3. Move materials to the fabrication shop
4. Shape burn on the computer numerically controlled burner
5. Move material to the hydraulic press
6. Die form the knuckle (whether hot or cold forming will be used will be determined later)
7. Inspect forming accuracy
8. Move material to the weld shop
9. Fit the knuckle to the welding fixture
10. Automatically weld vertical seams
11. Clean the welds
12. Inspect, examine and repair welds
13. Inspect the accuracy of the assembly
14. Move material to the paint shop
15. Auto blast and paint
16. Store during paint curing
17. Load on rail cars
18. Ship to site

E. TOWER CYLINDRICAL SHELL

All these steps are identical to Tower Cone Plate Sequence except:

4. Burning will be done on a CNC Gantry Burner
13. Ship to site

10.5.5 BLADE FABRICATION

The discussion of the blade fabrication is divided into the following sections: the center blade, inner blade, outer blade, tip cap, finger joint operation and surface finishing operation. The process development tasks are covered in another section..

10.5.5.1 Process Development

The wood blade fabrication process was based on GBI's proprietary process used in fabricating small wind turbine blades. The process required additional development, to enable it to fabricate large blades. This section covers the three major process development tasks: test sample fabrication, finger joint demonstration, and center blade demonstration. Only the first two tasks were completed.

Test Sample Fabrication - Process development began with the definition and fabrication of the samples required for evaluation. The purpose of the program was to establish the optimum epoxy spread rate, wood veneer design configurations, and article construction techniques. Many of the quality techniques were developed during this period. The most significant process developments resulting from this test work were:

- o Epoxy Spread Rate - 60 lbs. per 1000 sq. ft. of double glue line was selected as the spread rate.
- o Wood Veneer Overlap - 3 in. was selected as the wood veneer overlap.
- o Scarf Joints - Each veneer is scarfed at a slope of 12:1 to optimize strength.
- o Wood Veneer - Inspection and grading techniques were developed. The quality process is shown in Figure 10-3.
- o Epoxy - Quality techniques were developed and documented. The epoxy process flow is shown in Figure 10-4.
- o Moisture Control - The best moisture content of the veneer was determined to be between 7% and 9% of the veneer's weight. This standard evolved from observations made during the sample fabrication process. The results of sample fabrication development formed the basis for the process demonstration.

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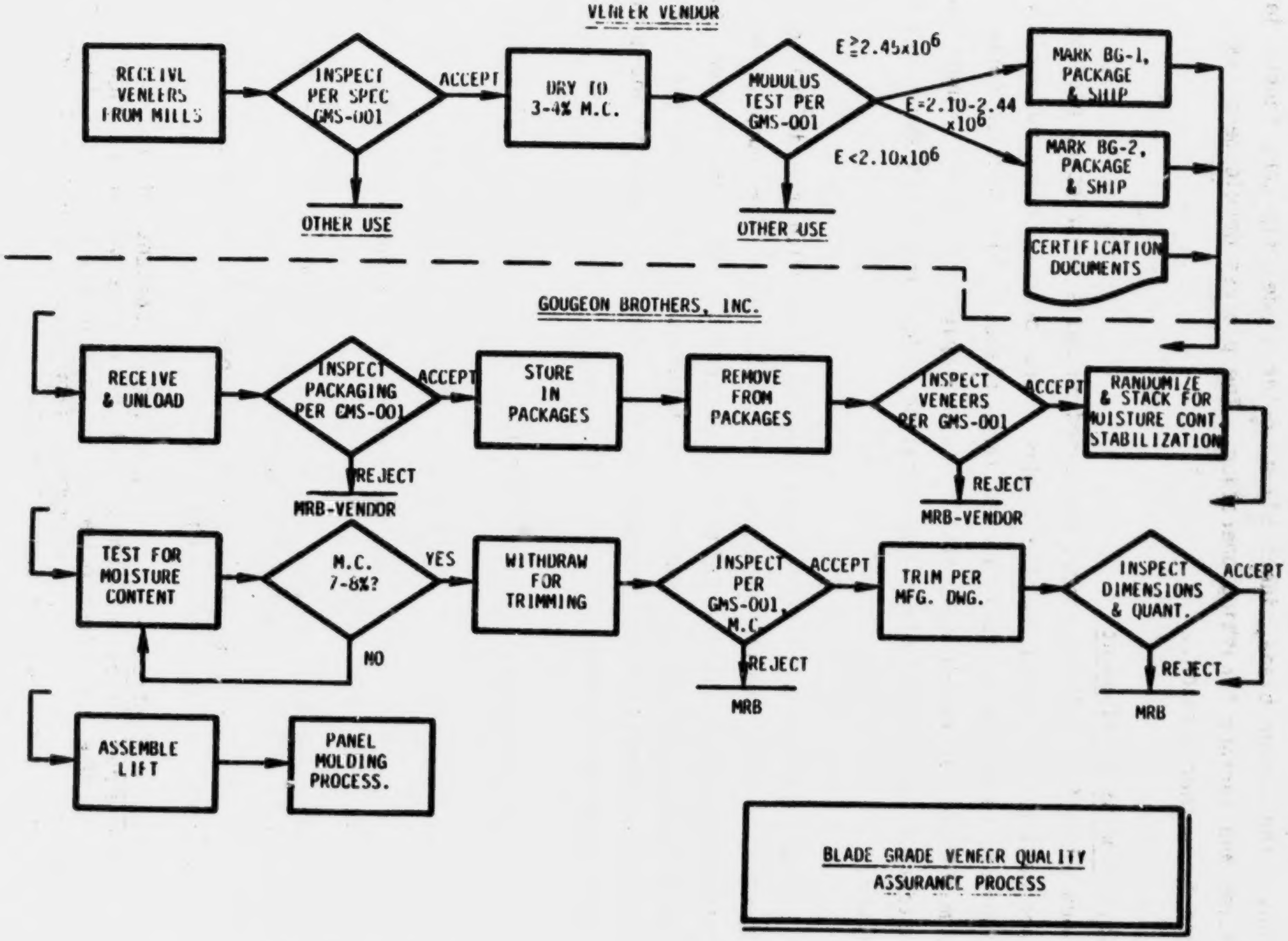
VENEER VENDOR
RECEIVE VENEERS FROM MILLS
INSPECT PER SPEC GMS-001
ACCEPT
OTHER USE
DRY TO 3-4% M.C.
MODULUS TEST PER GMS-001
E≧2.45x10^6
E=2.10-2.44 x10^6
E<2.10x10^6
OTHER USE
MARK BG-1, PACKAGE & SHIP
MARK BG-2, PACKAGE & SHIP
CERTIFICATION DOCUMENTS
GOUGEON BROTHERS, INC.
RECEIVE & UNLOAD
INSPECT PACKAGING PER GMS-001
ACCEPT
REJECT
MRB-VENDOR
STORE IN PACKAGES
REMOVE FROM PACKAGES
INSPECT VENEERS PER GMS-001
ACCEPT
REJECT
MRB-VENDOR
RANDOMIZE & STACK FOR MOISTURE CONT. STABILIZATION
TEST FOR MOISTURE CONTENT
M.C. 7-8%?
YES
NO
WITHDRAW FOR TRIMMING
INSPECT PER GMS-001, M.C.
ACCEPT
REJECT
MRB
TRIM PER MFG. DWG.
INSPECT DIMENSIONS & QUANT.
ACCEPT
REJECT
MRB
ASSEMBLE LIFT
PANEL MOLDING PROCESS.
BLADE GRADE VENEER QUALITY
ASSURANCE PROCESS

Figure 10-3 Blade Grade Veneer Quality Assurance Process

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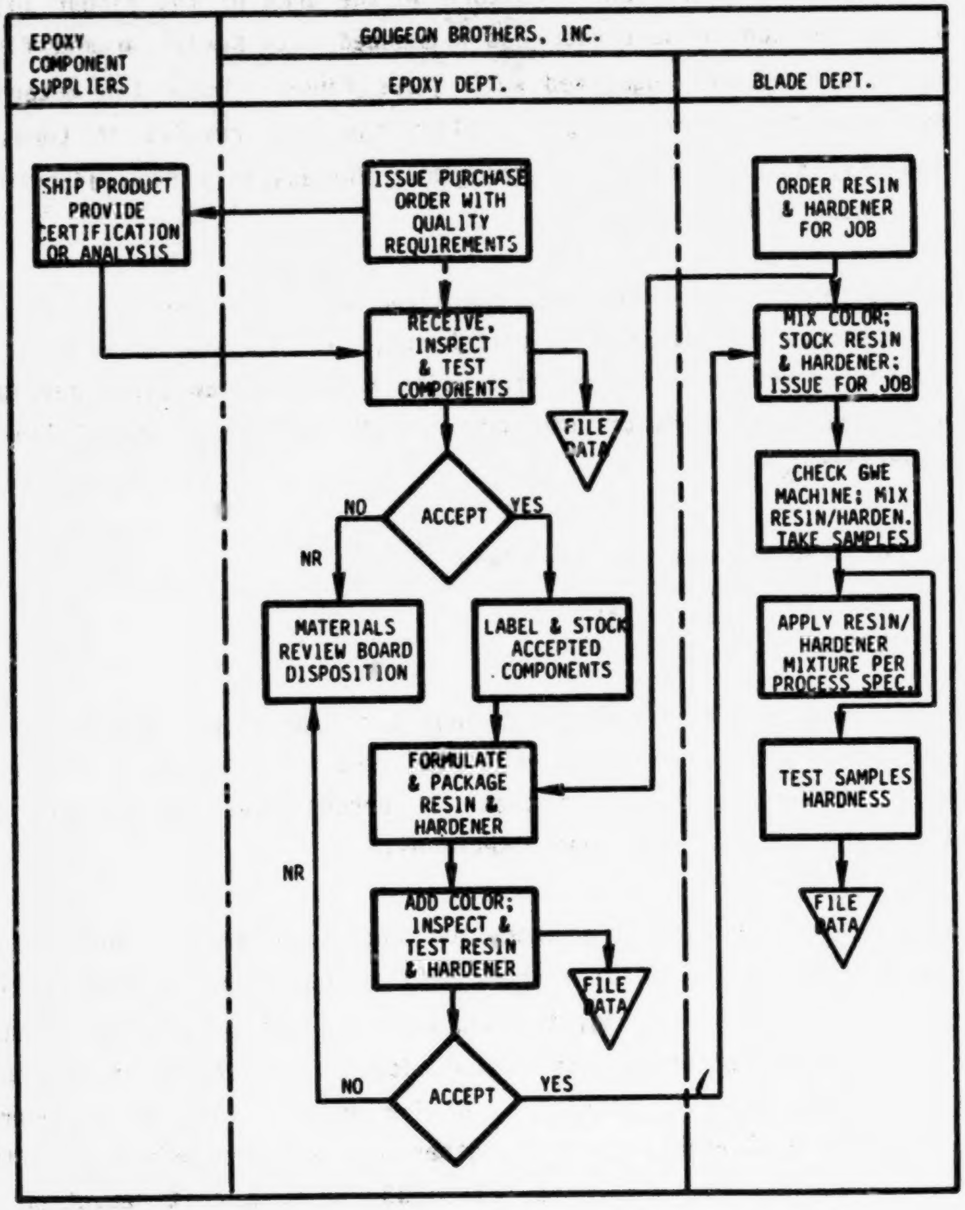
EPOXY COMPONENT SUPPLIERS
GOUGEON BROTHERS, INC.
EPOXY DEPT.
BLADE DEPT.
SHIP PRODUCT PROVIDE CERTIFICATION OR ANALYSIS
ISSUE PURCHASE ORDER WITH QUALITY REQUIREMENTS
ORDER RESIN & HARDENER FOR JOB
RECEIVE, INSPECT & TEST COMPONENTS
FILE DATA
MIX COLOR; STOCK RESIN & HARDENER; ISSUE FOR JOB
CHECK GWE MACHINE; MIX RESIN/HARDEN. TAKE SAMPLES
NO
ACCEPT
YES
NR
MATERIALS REVIEW BOARD DISPOSITION
LABEL & STOCK ACCEPTED COMPONENTS
APPLY RESIN/HARDENER MIXTURE PER PROCESS SPEC.
FORMULATE & PACKAGE RESIN & HARDENER
TEST SAMPLES HARDNESS
NR
ADD COLOR; INSPECT & TEST RESIN & HARDENER
FILE DATA
FILE DATA
NO
ACCEPT
YES

Figure 10-4 Blade Grade Epoxy Resin and Hardener Quality Assurance

b) Finger Joint Process Demonstration - The finger joint process development unit, as shown in Figure 10-5, developed and demonstrated the fabrication of large laminated wood panels, wood section assembly techniques, and finger joint forming techniques. The development used two modules that simulated the full scale blade structure in the area of the finger joint. Half of the section to be bonded was augmented with Kevlar aramid fibers and the other half was augmented with glass fiber. These two materials were evaluated to determine which yielded the best results in terms of producibility, stabilization and strength. The assembly flow diagram is shown in Figure 10-6.

GE machined the finger joints into completed modules. The work was done at GE's Apparatus Service Shop in Pittsburgh, PA. The machining was done with a large conventional boring mill using a special saw blade developed by North American Products of Jasper, IN, and had the following characteristics:

- 40 in. diameter saw blade
- 3/16 in. kerf
- 32 carbide teeth
- 6°, one way bevel

The finger joint process development unit was fabricated, and joined at the finger joint. Test specimens were evaluated. The results, listed in section 8, Volume II, indicated that the process was satisfactory for fabricating and joining large wooden sections.

The finger joint unit cutting operation uncovered several problems. Other methods for machining the finger joint, which might be less costly, were investigated. For example, the saw blade worked satisfactorily, but required several different set-ups, which added significantly to the cost of the operation. Alden Tool Company of Berlin, CT developed a tapered cutter set. GE evaluated this form cutter set and determined that the machine time would be reduced from 123 to 33 hours, a cost reduction of $40,000 per blade.

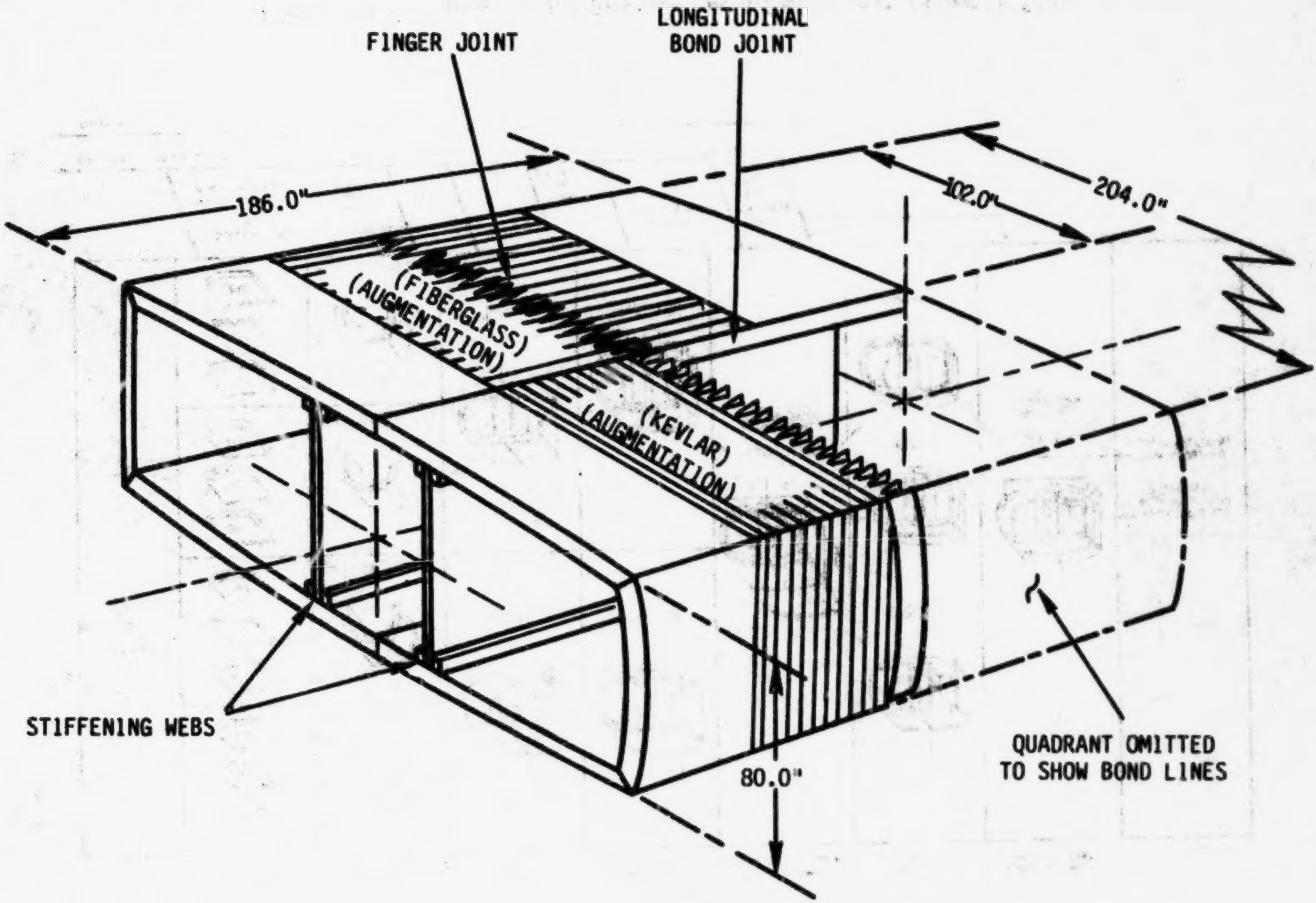
FINGER JOINT
LONGITUDINAL BOND JOINT
186.0"
102.0"
204.0"
(FIBERGLASS) (AUGMENTATION)
(KEVLAR) (AUGMENTATION)
STIFFENING WEBS
80.0"
QUADRANT OMITTED TO SHOW BOND LINES

Figure 10-5 Finger Joint Process Demonstration Unit

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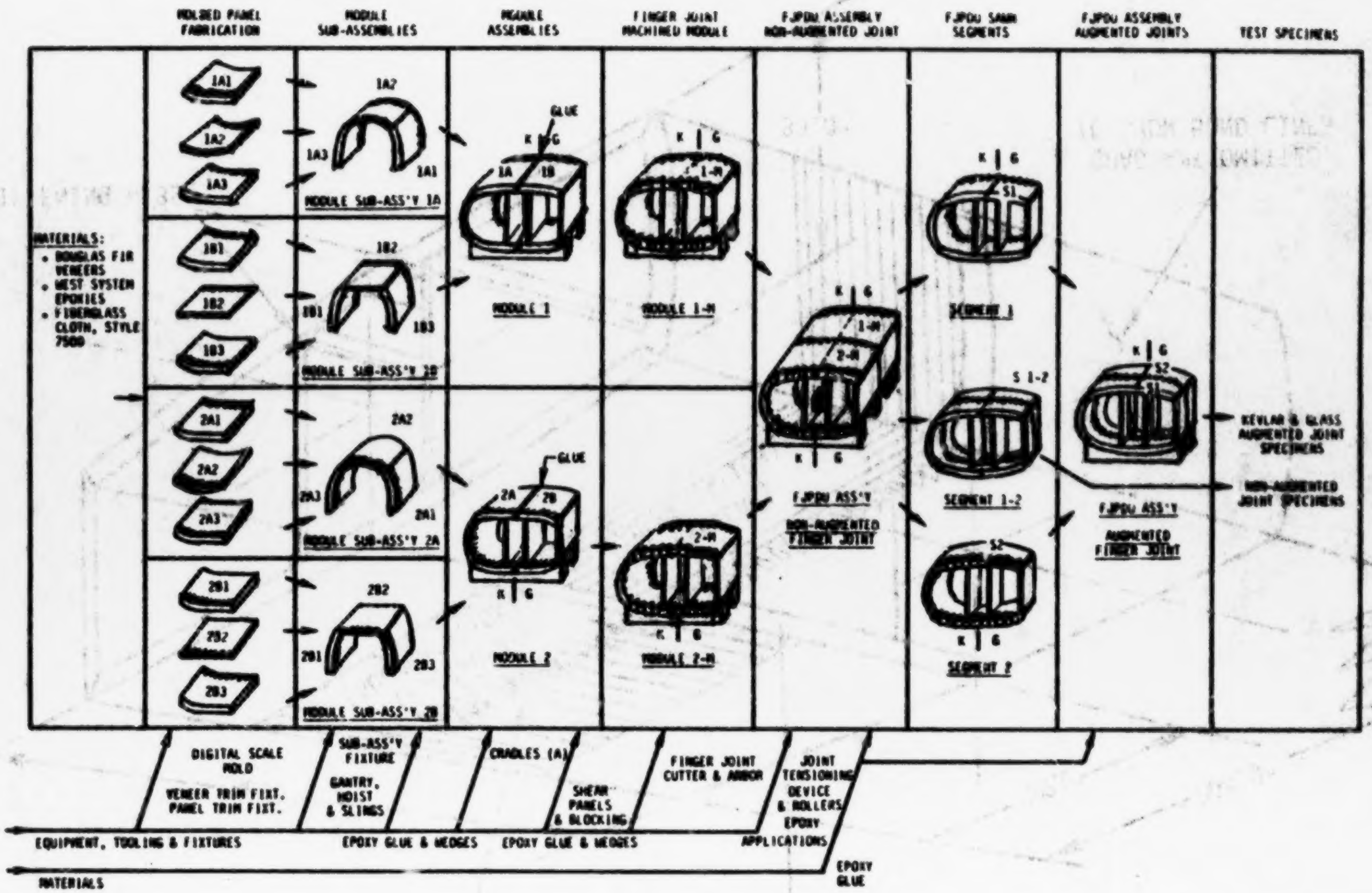
MOLDED PANEL FABRICATION
MODULE SUB-ASSEMBLIES
MODULE ASSEMBLIES
FINGER JOINT MACHINED MODULE
FJPDU ASSEMBLY NON-AUGMENTED JOINT
FJPDU SAWN SEGMENTS
FJPDU ASSEMBLY AUGMENTED JOINTS
TEST SPECIMENS
MATERIALS:
• DOUGLAS FIR VENEERS
• WEST SYSTEM EPOXIES
• FIBERGLASS CLOTH, STYLE 7500
1A1
1A2
1A3
1B1
1B2
1B3
2A1
2A2
2A3
2B1
2B2
2B3
MODULE SUB-ASS'Y 1A
MODULE SUB-ASS'Y 1B
MODULE SUB-ASS'Y 2A
MODULE SUB-ASS'Y 2B
GLUE
K
G
1A
1B
2A
2B
MODULE 1
MODULE 2
1-M
2-M
MODULE 1-M
MODULE 2-M
FJPDU ASS'Y
NON-AUGMENTED FINGER JOINT
S1
S2
S 1-2
SEGMENT 1
SEGMENT 1-2
SEGMENT 2
FJPDU ASS'Y
AUGMENTED FINGER JOINT
KEVLAR & GLASS AUGMENTED JOINT SPECIMENS
NON-AUGMENTED JOINT SPECIMENS
DIGITAL SCALE MOLD
VENEER TRIM FIXT.
PANEL TRIM FIXT.
SUB-ASS'Y FIXTURE
GANTRY, HOIST & SLINGS
CRADLES (A)
SHEAR PANELS & BLOCKING
FINGER JOINT CUTTER & ARBOR
JOINT TENSIONING DEVICE & ROLLERS
EPOXY APPLICATIONS
EQUIPMENT, TOOLING & FIXTURES
EPOXY GLUE & WEDGES
EPOXY GLUE & WEDGES
MATERIALS
EPOXY GLUE

Figure 10-6 Finger Joint Process Development Unit Assembly Flow

The significant results of the finger joint development were:

- o **Augmentation** - Experiments determined how the dimensions of plain or augmented laminated wood were affected by changes in humidity. The experiments indicated that the laminae needed to be augmented. Either glass fiber or Kevlar would be satisfactory, according to tests described in section 8, Volume II.

- o **Panel Lift Off** - During the fabrication of the panels, each panel separated from the mold along the edges parallel to the grain direction. Experimentation showed that the separation was caused by heat, which built up in thick sections as the epoxy gave off heat during the cure cycle. This problem occurred with a single build-up of 4 in. of laminae, but did not occur in a single build-up of 1 in. Future applications must limit the temperature rise during the cure.

- o **Establishment of Preliminary Specifications** - The experience of fabrication resulted in the following preliminary specifications:

  Veneer Specification GMS-001
  Longitudinal Wedge Glue Gap: 0.01 in. to 0.10 in.
  Longitudinal Gap in Laminae: 0.125 in. to 0.5 in.
  Veneer Overlap: +/- 0.250 in. in up to 5% of joints
  Vacuum Gage Pressure: 20.0 to 25.0 in. of Hg
  Epoxy Cure Period:
    Under Vacuum 8 hours
    Before Loading 24 hours
  Longitudinal Wedge Construction:
    10" thick Douglas fir veneer is laminated to a thickness equivalent to the thickness of the skin to which it joins, using standard epoxy and bagging techniques. After the cure, the wedge is cut to the required wedge angle and then scarfed to the required length and a slope of 12:1.

c) Center Blade Process Demonstration - The center blade process development unit is shown in Figure 10-7. Its purpose was to develop and demonstrate the actual usage of large blade molds and equipment, refine large panel fabrication procedures and construction techniques unique to the center blade section. The development unit design is a full-size cut-out of the center blade. These processes would have been developed by this demonstration:

- o The techniques and procedures used to fabricate the bolster assemblies:

  Douglas fir and wet glass fiber layering.

  Installation and alignment of teeter bearings and brake shaft attachments.

  Installation and alignment of the bolster and the center blade.

- o Large panel fabrication using gantries and equipment designed for large blades.
- o The techniques and procedures necessary to assemble the center blade, shear webs, bolsters, teeter shaft and blocking.

The center blade process development unit did not progress past the planning stage.

10.5.5.2 Center Blade Section

The basic process used in the fabrication of the blade components is shown in Figure 10-8. The parts that form the center blade are shown in Figure 10-9. The longitudinal joints were formed using the wedge joint configuration, shown in Figure 10-10. These laminated wedges facilitate the longitudinal bonding of the very long panels. The panels are located in fixtures, secured and then bonded together with epoxy, using the wedges to ensure bonding along the joint length.

Subassemblies HA and HB are identical and are assembled first. The shear webs, HC1 and HC2, and miscellaneous blocking around the teeter area are installed in these subassemblies. The resulting sections are joined to form the center section. Each end of this center section is machined, using the process developed by the finger joint process development unit, described in 10.5.5.1.

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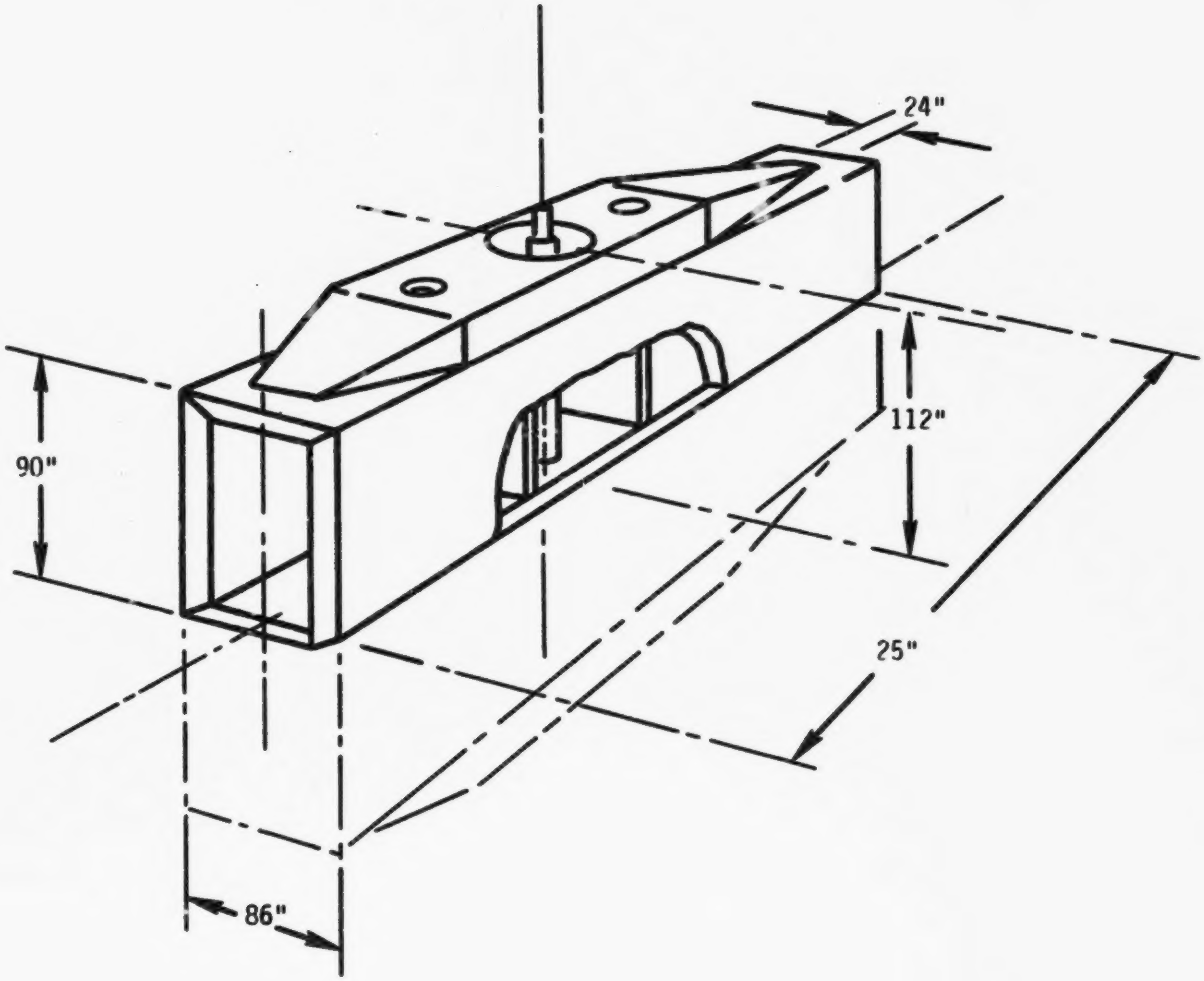
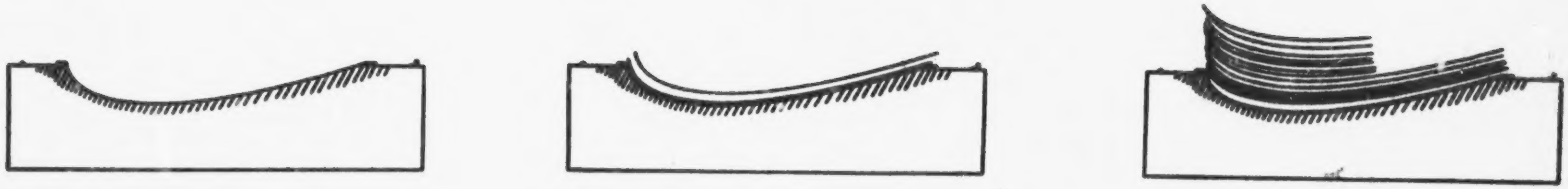

24"
90"
112"
25"
86"

Figure 10-7 Center Blade Process Demonstration Unit



BASE MOLD

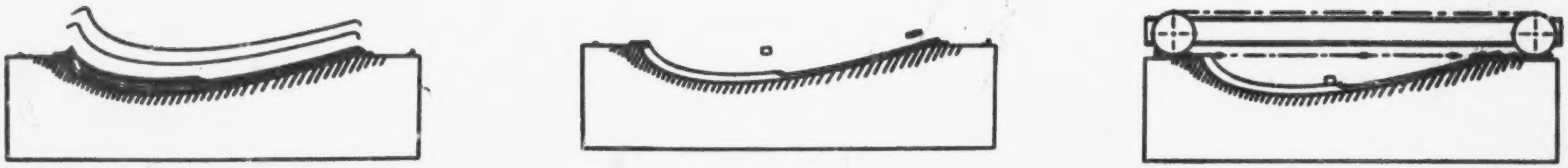
1.

EXTERIOR FIBERGLASS SKIN WET-OUT IN BASIC MOLD

2.

VENEER PLACED IN MOLD

3.



INTERIOR FIBERGLASS PLACED ON ON VENEER PRIOR TO VACUUM

4.

EPOXY IN VARIOUS BLOCKING AFTER VACUUM BAG REMOVAL

5.

SAW TRIM MATING JOINTS AND REMOVE FROM MOLD

6.

Figure 10-8 Basic Blade Fabrication Process

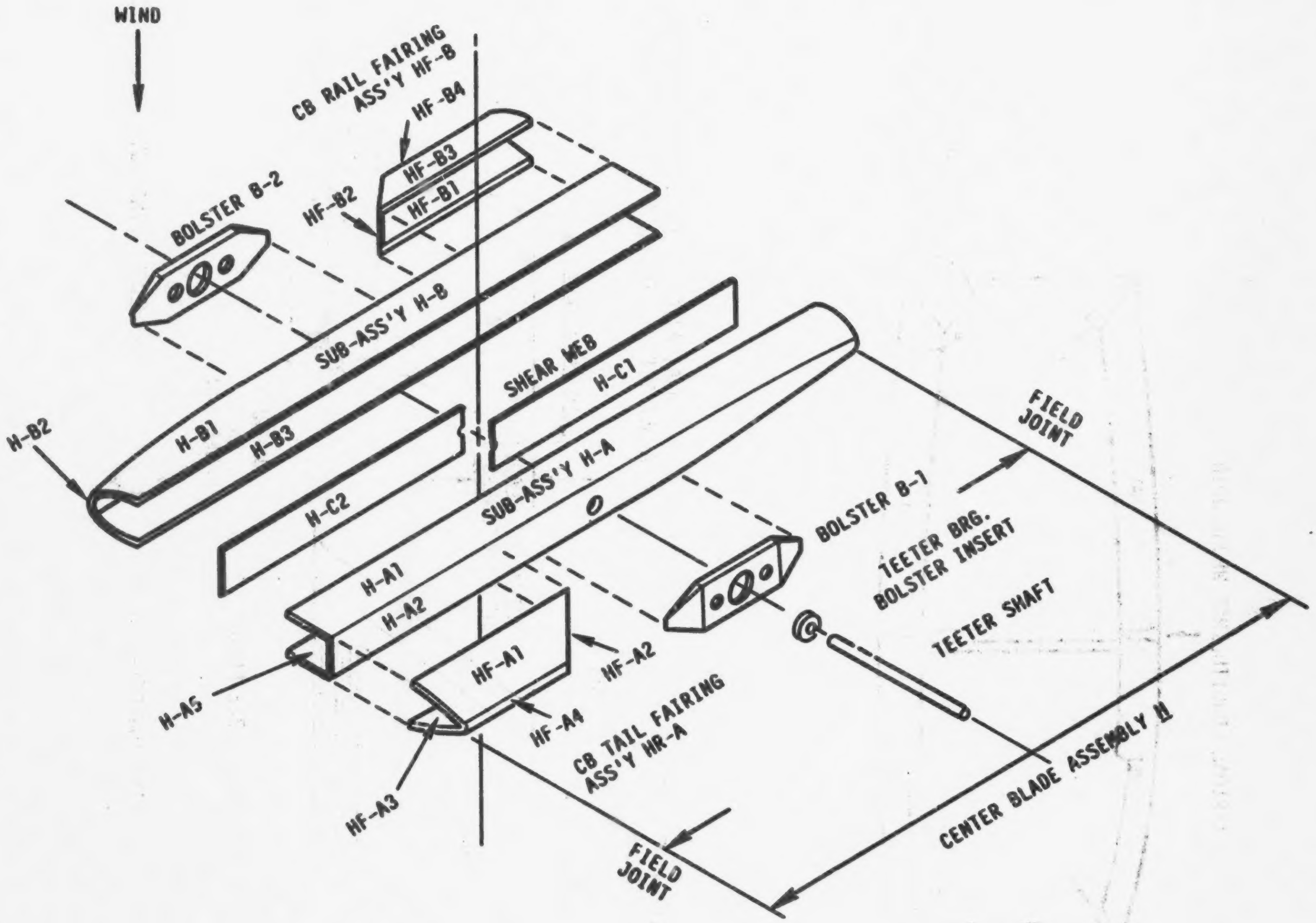
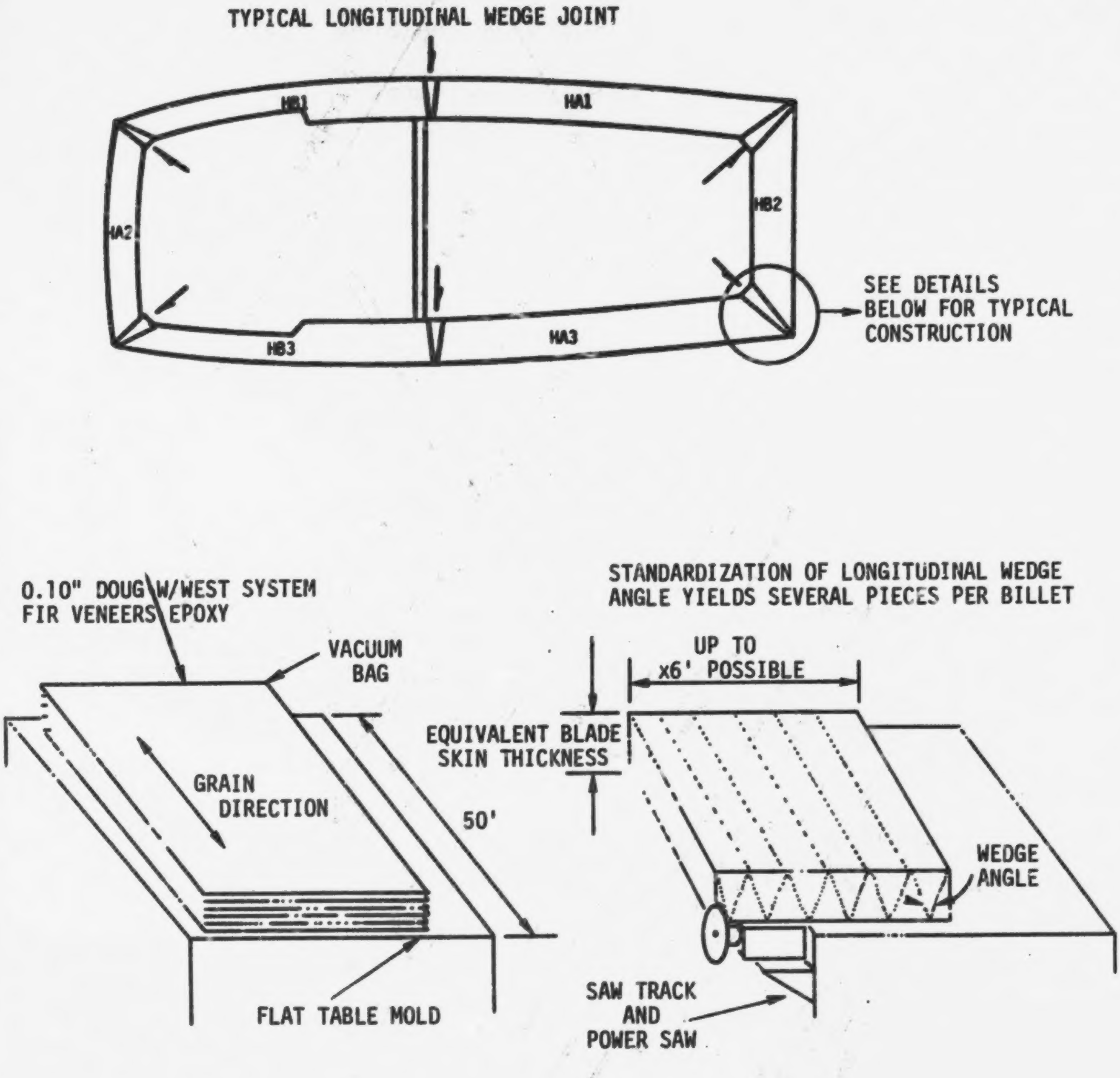

WIND
CB RAIL FAIRING ASS'Y HF-B
HF-B4
HF-B3
HF-B1
HF-B2
BOLSTER B-2
SUB-ASS'Y H-B
SHEAR WEB
H-C1
H-B2
H-B1
H-B3
H-C2
SUB-ASS'Y H-A
FIELD JOINT
BOLSTER B-1
TEETER BRG. BOLSTER INSERT
TEETER SHAFT
H-A1
H-A2
H-A5
HF-A1
HF-A2
HF-A4
HF-A3
CB TAIL FAIRING ASS'Y HR-A
CENTER BLADE ASSEMBLY II
FIELD JOINT

Figure 10-9 Center Blade Assembly


TYPICAL LONGITUDINAL WEDGE JOINT
HB1
HA1
HA2
HB2
HB3
HA3
SEE DETAILS BELOW FOR TYPICAL CONSTRUCTION
0.10" DOUG FIR VENEERS
W/WEST SYSTEM EPOXY
VACUUM BAG
GRAIN DIRECTION
50'
FLAT TABLE MOLD
STANDARDIZATION OF LONGITUDINAL WEDGE ANGLE YIELDS SEVERAL PIECES PER BILLET
UP TO x6' POSSIBLE
EQUIVALENT BLADE SKIN THICKNESS
WEDGE ANGLE
SAW TRACK AND POWER SAW

- BILLET LAMINATION DETAILS -

- WEDGE JOINT CUTTING DETAILS -

Figure 10-10 Center Blade Wedge Joint Configuration and Typical Construction

The two bolsters, B1 and B2, and the two trailing edge fairings are made as subassemblies and given a trial fitting before they are shipped. These items, and the bearings and teeter shaft are assembled in the field.

10.5.5.3 Inner Blade Section

The process used to fabricate and assemble the inner blade assembly is described in section 10.5.5.2. Two identical inner blades are fabricated. The parts that form the inner blades are shown in Figure 10-11. The longitudinal joints are formed using the wedge joint configuration, shown in Figure 10-12. The M1-A and M1-B subassemblies are assembled first, and joined to form the M1 inner blade. Each end of the inner blade is machined to form the finger joints that mate with matching joints of the center blade and outer blade. The trailing edge assemblies are fabricated separately and given a trial fitting to the inner blade before they are shipped. These items, and hydraulic and electrical lines are assembled in the field.

10.5.5.4 Outer Blade Section

The process used in fabricating and assembling the outer blade assembly is described in section 10.5.5.2. Two identical outer blades are fabricated. The parts that form the outer blades are shown in Figure 10-13. The longitudinal joint configuration is also shown in this figure. The outer panels, T1-A1 and T1-A2, and the shear webs, T1-B1 and T1-B2, are assembled using the outer panel mold as an assembly fixture. Internal blocking and chordwise sections, which accept the studs for the ailerons, are installed. The rear panels, T1-C1 and T1-C2, are assembled using the longitudinal wedge joints. The stud holes are drilled and reamed, and the finger joints, which match the outer blade joints, are cut. The studs that hold the ailerons are bonded in place with epoxy. The inner blade, cap, and aileron sections are given a trial fitting. Final finishing is done before shipment.

10.5.5.5 Tip Cap Fabrication

Three processes were evaluated for use in the fabrication of the tip cap. These processes were molded glass fiber, carved wood with glass fiber skin and formed aluminum sheets. The molded glass fiber process was selected as the baseline on the basis of cost estimates and discussions with suppliers. A supplier was not selected, but one would have been selected on a competitive

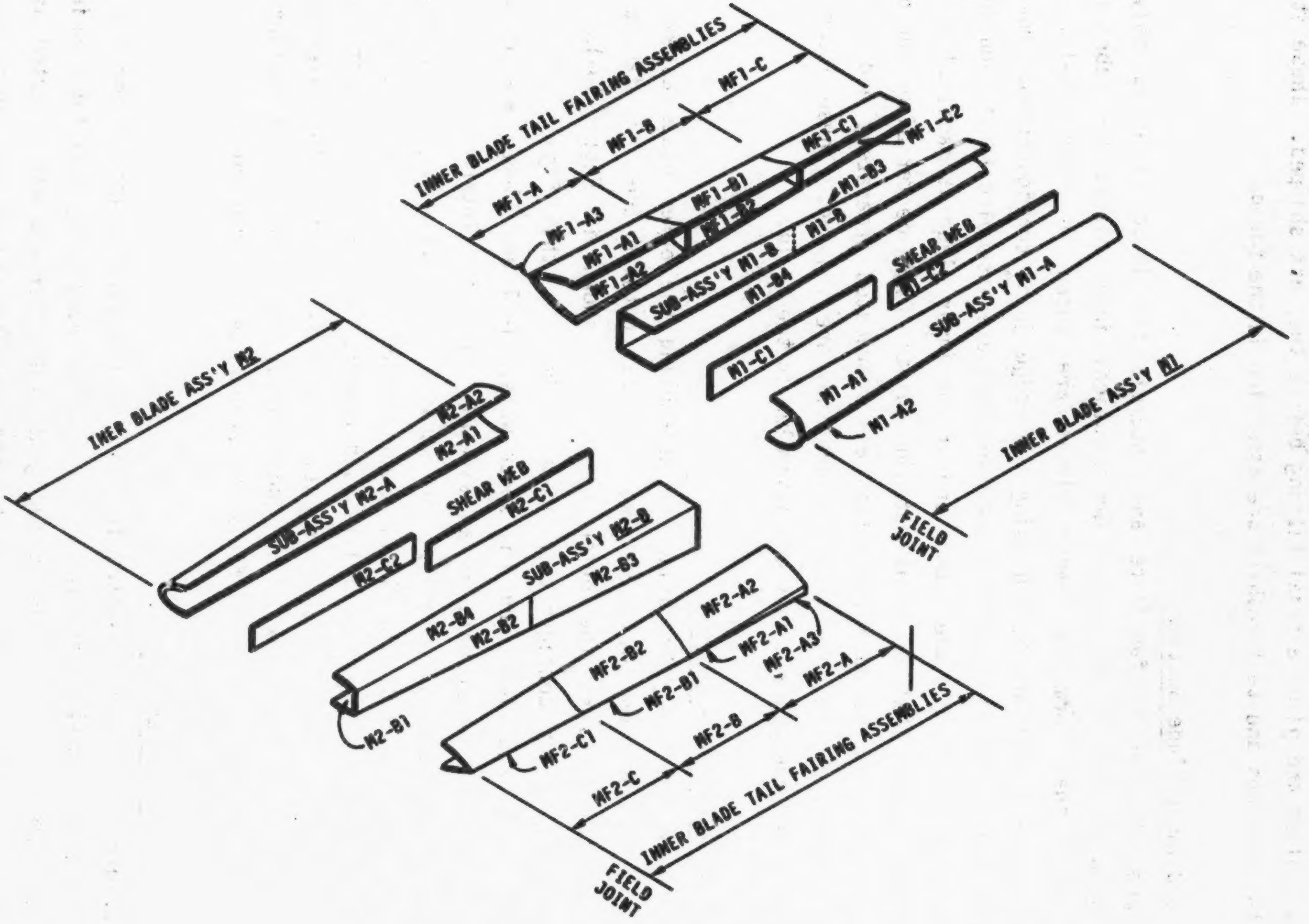

INNER BLADE TAIL FAIRING ASSEMBLIES
MF1-A
MF1-B
MF1-C
MF1-C1
MF1-C2
MF1-B1
MF1-B2
MF1-A3
MF1-A1
MF1-A2
M1-B3
M1-B
SUB-ASS'Y M1-B
M1-B4
SHEAR WEB
M1-C2
M1-C1
SUB-ASS'Y M1-A
M1-A1
M1-A2
INNER BLADE ASS'Y M1
FIELD JOINT
INNER BLADE ASS'Y M2
M2-A2
M2-A1
SUB-ASS'Y M2-A
SHEAR WEB
M2-C1
M2-C2
SUB-ASS'Y M2-B
M2-B3
M2-B4
M2-B2
M2-B1
MF2-A2
MF2-A1
MF2-A3
MF2-B2
MF2-B1
MF2-A
MF2-B
MF2-C1
MF2-C
INNER BLADE TAIL FAIRING ASSEMBLIES
FIELD JOINT

Figure 10-11 Inner Blade Assembly

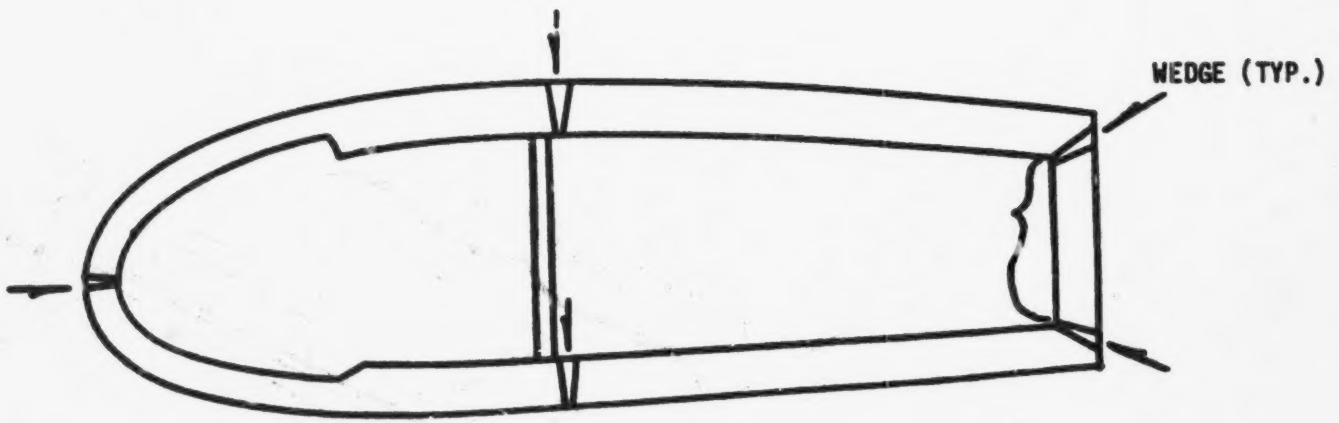


Figure 10-12 Inner Blade Wedge Joint Configuration

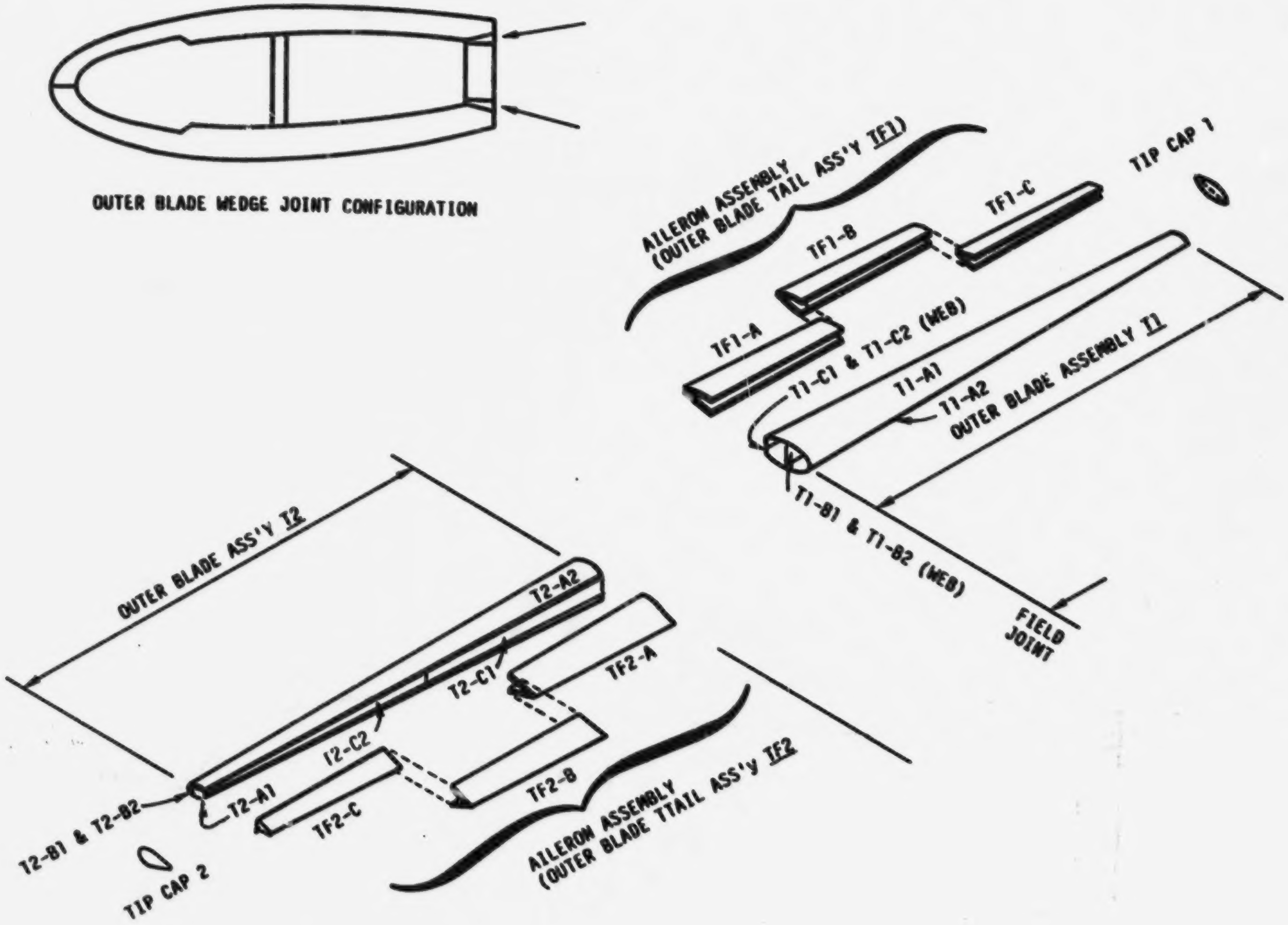

OUTER BLADE WEDGE JOINT CONFIGURATION
AILERON ASSEMBLY (OUTER BLADE TAIL ASS'Y TF1)
TF1-A
TF1-B
TF1-C
TIP CAP 1
T1-C1 & T1-C2 (WEB)
T1-A1
T1-A2
OUTER BLADE ASSEMBLY T1
T1-B1 & T1-B2 (WEB)
FIELD JOINT
OUTER BLADE ASS'Y T2
T2-A2
T2-C1
T2-C2
T2-A1
T2-B1 & T2-B2
TF2-A
TF2-B
TF2-C
TIP CAP 2
AILERON ASSEMBLY (OUTER BLADE TTAIL ASS'Y TF2

Figure 10-13 Outer Blade Assembly

basis. The plan was to fabricate the tip, fit the caps on the outer blade at the blade manufacturing facility, disassemble the caps and outer blade, and ship them to the site for a field assembly. The trial fitting would assure a proper fitting at the field assembly.

10.5.5.6 Finger Joint Fabrication

The wooden blade contains four finger joints that will be joined during the field assembly. The process of forming and joining these fingers was developed and demonstrated with the finger joint process development unit, described in section 10.5.5.1. This technology would be used to form and join the blade sections.

A portable traveling column mill, as shown in Figure 10-14, would be used at the blade manufacturing plant. This specially built machine would be provided by the GE's Apparatus Service Shop in Detroit. The development of the machine used the experience gained in cutting the finger joint process development unit. Each joint would be fully inspected, and a trial fitting made before shipping, so that the joint would fit properly in the field assembly.

10.5.5.7 Surface Finishing

The process for forming the wood blade sections, wet layering in female molds, results in a smooth surface with close tolerances. The panels are joined at longitudinal joints to form the main blade sections. The joints are sanded and covered with glass fiber to keep moisture out. The joints are sanded again, and painted according to the applicable drawing before shipment.

10.5.6 FACTORY AREA COMPONENT ASSEMBLY

This section describes the sequence of the factory and component assembly of the MOD-5A wind turbine generator, as shown in Figure 10-15.

To ensure that key components of the nacelle will fit and operate properly at the field site, a trial assembly of the important parts must be made in the factory as shown in Figure 10-16.

First, a suitable foundation will be prepared on the factory floor, to support the assembly. If the floor is adequate, then a yaw foundation assembly ring may be bolted directly to the floor with anchor bolts and grouting. The yaw

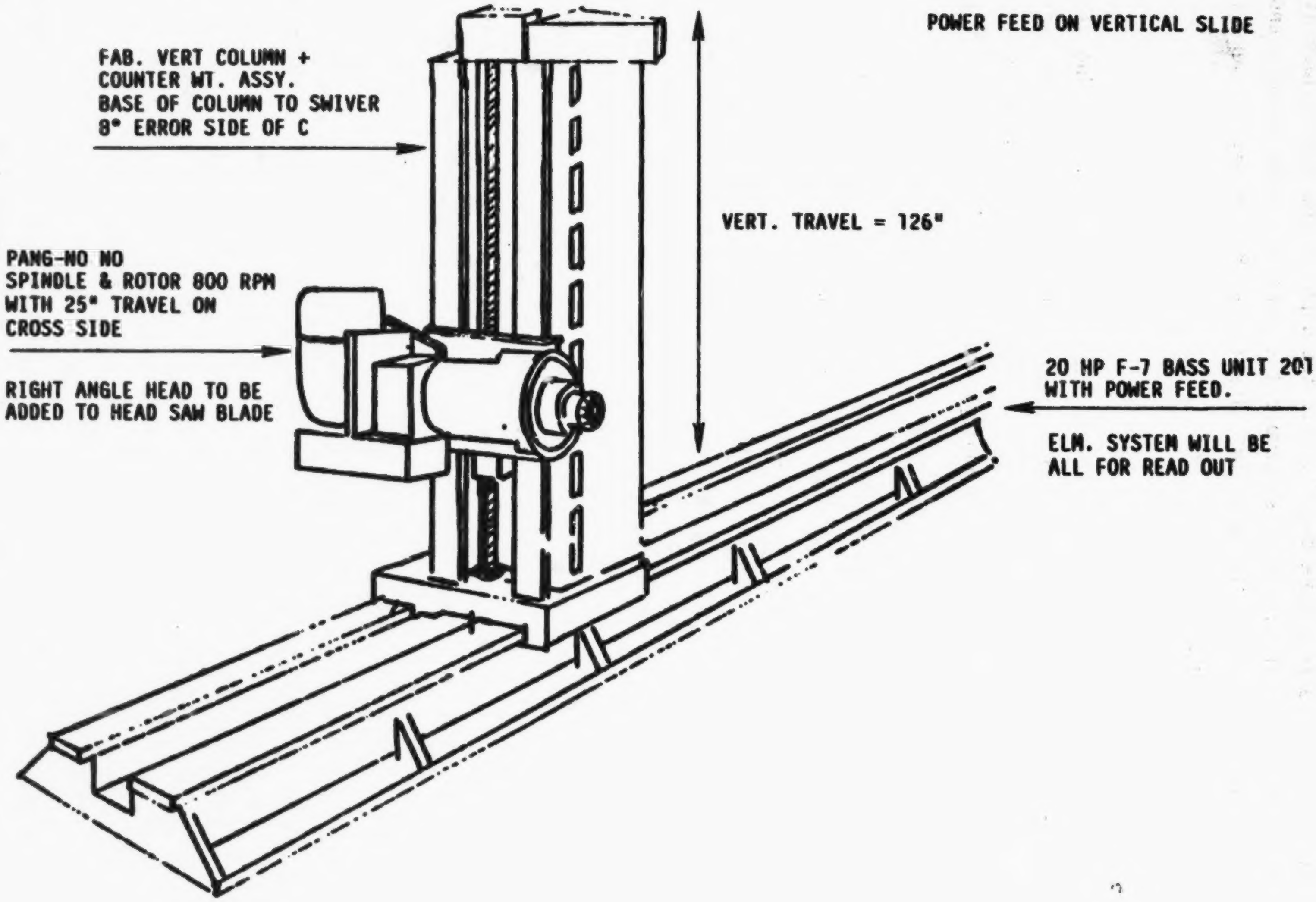

POWER FEED ON VERTICAL SLIDE
FAB. VERT COLUMN + COUNTER WT. ASSY. BASE OF COLUMN TO SWIVER 8° ERROR SIDE OF C
VERT. TRAVEL = 126"
PANG-NO NO SPINDLE & ROTOR 800 RPM WITH 25" TRAVEL ON CROSS SIDE
RIGHT ANGLE HEAD TO BE ADDED TO HEAD SAW BLADE
20 HP F-7 BASS UNIT 201 WITH POWER FEED.
ELM. SYSTEM WILL BE ALL FOR READ OUT

Figure 10-14 Portable Traveling Column Mill

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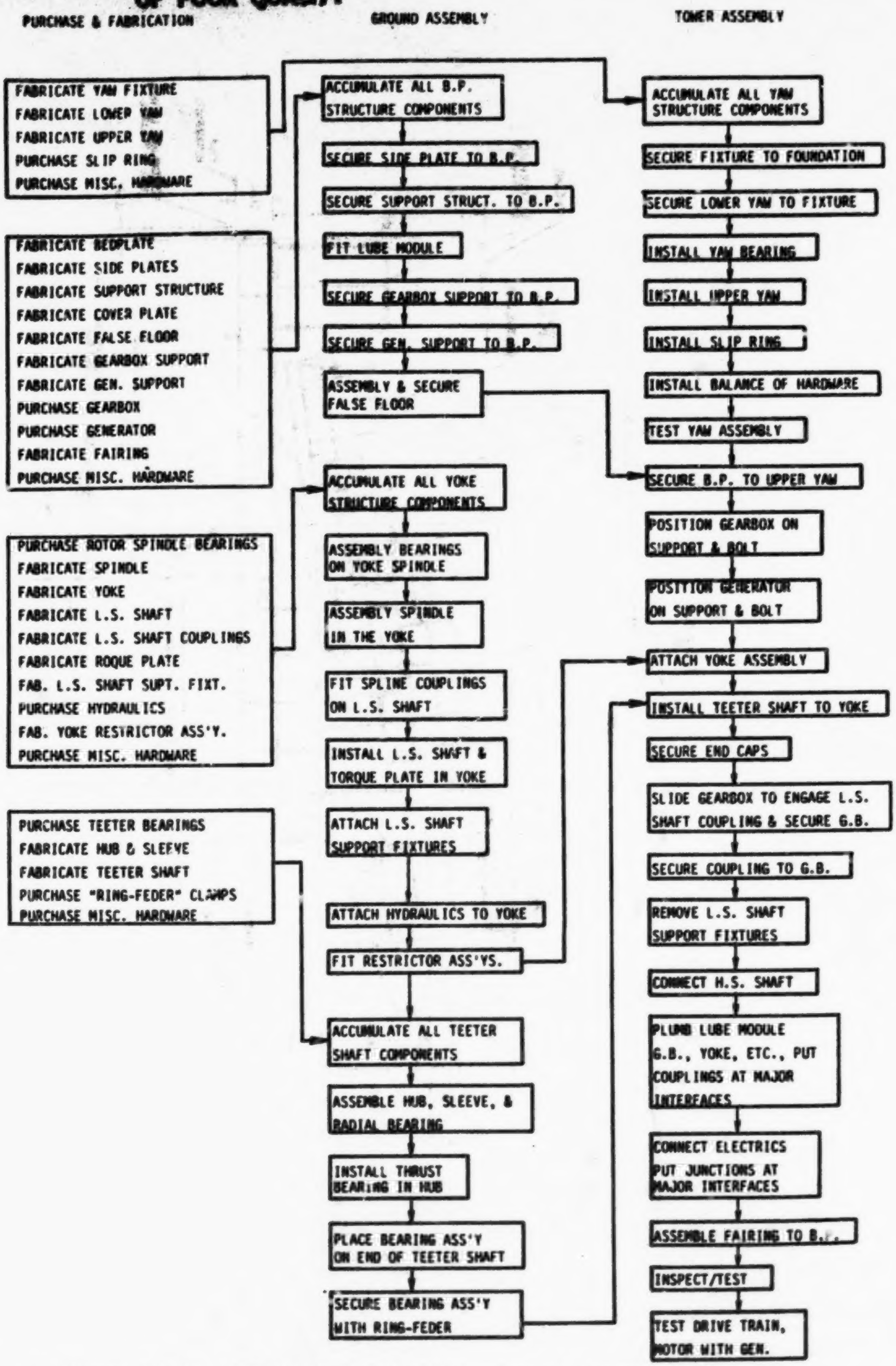
PURCHASE & FABRICATION
GROUND ASSEMBLY
TOWER ASSEMBLY
FABRICATE YAW FIXTURE
FABRICATE LOWER YAW
FABRICATE UPPER YAW
PURCHASE SLIP RING
PURCHASE MISC. HARDWARE
FABRICATE BEDPLATE
FABRICATE SIDE PLATES
FABRICATE SUPPORT STRUCTURE
FABRICATE COVER PLATE
FABRICATE FALSE FLOOR
FABRICATE GEARBOX SUPPORT
FABRICATE GEN. SUPPORT
PURCHASE GEARBOX
PURCHASE GENERATOR
FABRICATE FAIRING
PURCHASE MISC. HARDWARE
PURCHASE ROTOR SPINDLE BEARINGS
FABRICATE SPINDLE
FABRICATE YOKE
FABRICATE L.S. SHAFT
FABRICATE L.S. SHAFT COUPLINGS
FABRICATE ROQUE PLATE
FAB. L.S. SHAFT SUPT. FIXT.
PURCHASE HYDRAULICS
FAB. YOKE RESTRICTOR ASS'Y.
PURCHASE MISC. HARDWARE
PURCHASE TEETER BEARINGS
FABRICATE HUB & SLEEVE
FABRICATE TEETER SHAFT
PURCHASE "RING-FEDER" CLAMPS
PURCHASE MISC. HARDWARE
ACCUMULATE ALL B.P. STRUCTURE COMPONENTS
SECURE SIDE PLATE TO B.P.
SECURE SUPPORT STRUCT. TO B.P.
FIT LUBE MODULE
SECURE GEARBOX SUPPORT TO B.P.
SECURE GEN. SUPPORT TO B.P.
ASSEMBLY & SECURE FALSE FLOOR
ACCUMULATE ALL YOKE STRUCTURE COMPONENTS
ASSEMBLY BEARINGS ON YOKE SPINDLE
ASSEMBLY SPINDLE IN THE YOKE
FIT SPLINE COUPLINGS ON L.S. SHAFT
INSTALL L.S. SHAFT & TORQUE PLATE IN YOKE
ATTACH L.S. SHAFT SUPPORT FIXTURES
ATTACH HYDRAULICS TO YOKE
FIT RESTRICTOR ASS'YS.
ACCUMULATE ALL TEETER SHAFT COMPONENTS
ASSEMBLE HUB, SLEEVE, & RADIAL BEARING
INSTALL THRUST BEARING IN HUB
PLACE BEARING ASS'Y ON END OF TEETER SHAFT
SECURE BEARING ASS'Y WITH RING-FEDER
ACCUMULATE ALL YAW STRUCTURE COMPONENTS
SECURE FIXTURE TO FOUNDATION
SECURE LOWER YAW TO FIXTURE
INSTALL YAW BEARING
INSTALL UPPER YAW
INSTALL SLIP RING
INSTALL BALANCE OF HARDWARE
TEST YAW ASSEMBLY
SECURE B.P. TO UPPER YAW
POSITION GEARBOX ON SUPPORT & BOLT
POSITION GENERATOR ON SUPPORT & BOLT
ATTACH YOKE ASSEMBLY
INSTALL TEETER SHAFT TO YOKE
SECURE END CAPS
SLIDE GEARBOX TO ENGAGE L.S. SHAFT COUPLING & SECURE G.B.
SECURE COUPLING TO G.B.
REMOVE L.S. SHAFT SUPPORT FIXTURES
CONNECT H.S. SHAFT
PLUMB LUBE MODULE G.B., YOKE, ETC., PUT COUPLINGS AT MAJOR INTERFACES
CONNECT ELECTRICS PUT JUNCTIONS AT MAJOR INTERFACES
ASSEMBLE FAIRING TO B.P.
INSPECT/TEST
TEST DRIVE TRAIN, MOTOR WITH GEN.

Figure 10-15 MOD-5A Factory and Component Assembly Flow

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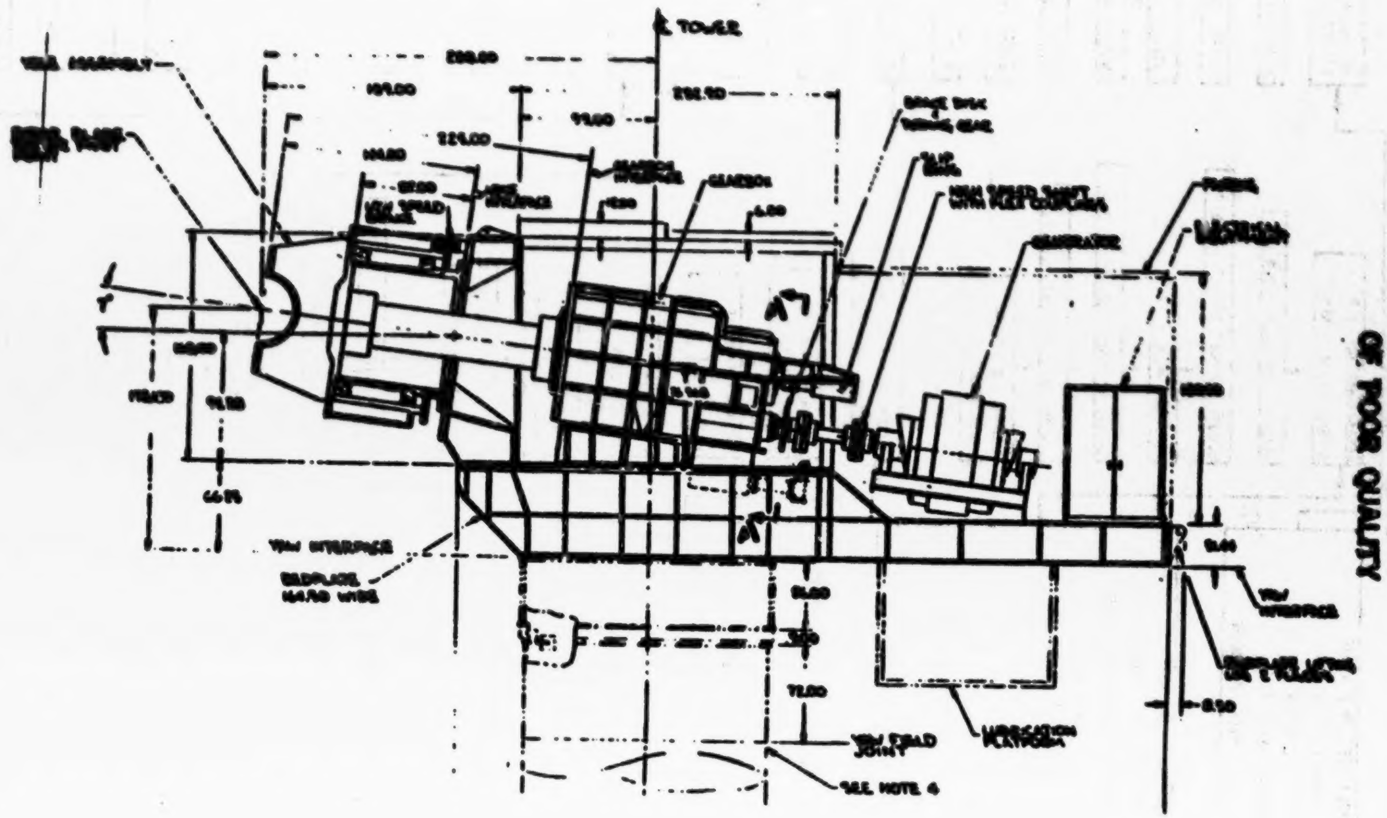
℄ TOWER
YAW ASSEMBLY
288.00
109.00
252.50
79.00
224.00
144.00
57.00
LOW SPEED BEARING
GEARBOX INTERFACE
GEARBOX
4.00
BRAKE DISK & TURNING GEAR
SLIP RING
HIGH SPEED SHAFT WITH FLEX COUPLINGS
GENERATOR
FAIRING
ELECTRICAL EQUIPMENT
YAW INTERFACE
36.00
3.00
72.00
YAW FIXED JOINT
SEE NOTE 4
LUBRICATION PLATFORM
8.50
46.75

Figure 10-16 Factory and Component Assembly

drive subsystem is assembled to the foundation ring. The subsystem includes bearings, actuators, the brake caliper system, slip ring, hydraulic components and the upper and lower structure. The bedplate structure is fitted to the top of the yaw subsystem and bolted down, then the rotor adapter and side support structures are mounted.

With these structures assembled, the gearbox and generator are lifted and attached to their mountings using the factory's crane. The yoke and spindle shaft are fitted with two rotor bearings, retainers, seals, torque plate, low speed brake disc, and the forward low speed shaft coupling, which engages the torque plate splines. This assembly is positioned so that the aft low speed shaft coupling engages the gearbox splines, and is carefully slid into position. The fixed spindle is bolted to the face plate of the rotor adapter structure.

The teeter bearings are preassembled to the teeter shaft, which is raised to simulate conditions of the installation in the field and to try special scaffolding. After the bearings are installed in the yoke cradle, the caps are positioned and bolted to the yoke.

The high speed shaft is bolted to the gearbox output shaft, and secured. The generator shaft is aligned, shimmed, and fastened to the high speed shaft coupling. The generator base is bolted to the support structure.

The lube module is installed to the bedplate, with the electrical equipment cabinets. The electrical and hydraulic lines are connected. The assembly is inspected and the rotor adapter top covers, fairing and platforms are installed. The component assembly is ready for quality assurance and engineering tests.

Disassembly for shipment requires removal of the fairing, generator, high speed shaft, top cover, yoke spindle assembly, gearbox, rotor adapter, side supports, teeter shaft assembly, electrical and hydraulic equipment, and the bedplate and yaw subsystem. Figure 10-17 contains a disassembly flow diagram.

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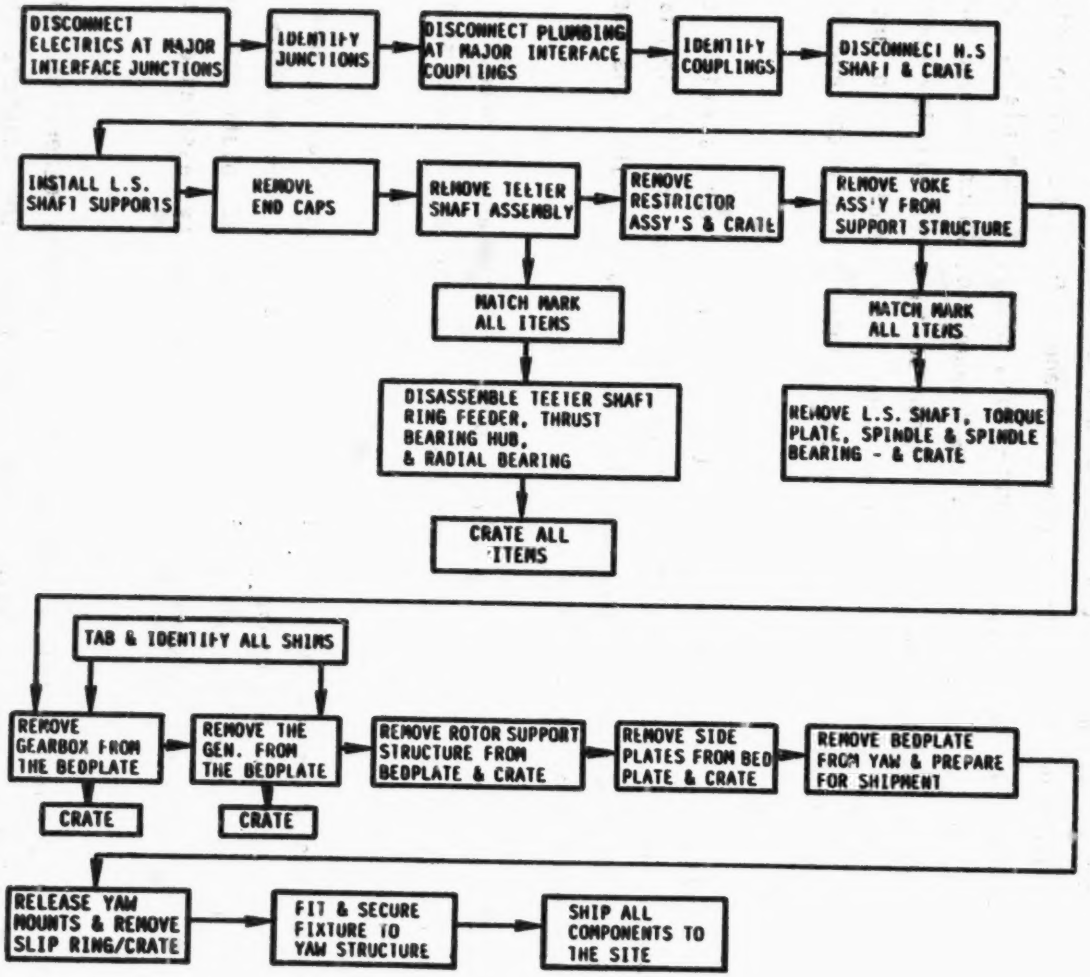

DISCONNECT ELECTRICS AT MAJOR INTERFACE JUNCTIONS
IDENTIFY JUNCTIONS
DISCONNECT PLUMBING AT MAJOR INTERFACE COUPLINGS
IDENTIFY COUPLINGS
DISCONNECT H.S SHAFT & CRATE
INSTALL L.S. SHAFT SUPPORTS
REMOVE END CAPS
REMOVE TEETER SHAFT ASSEMBLY
REMOVE RESTRICTOR ASSY'S & CRATE
REMOVE YOKE ASS'Y FROM SUPPORT STRUCTURE
MATCH MARK ALL ITEMS
DISASSEMBLE TEETER SHAFT RING FEEDER, THRUST BEARING HUB, & RADIAL BEARING
CRATE ALL ITEMS
MATCH MARK ALL ITEMS
REMOVE L.S. SHAFT, TORQUE PLATE, SPINDLE & SPINDLE BEARING - & CRATE
TAB & IDENTIFY ALL SHIMS
REMOVE GEARBOX FROM THE BEDPLATE
CRATE
REMOVE THE GEN. FROM THE BEDPLATE
CRATE
REMOVE ROTOR SUPPORT STRUCTURE FROM BEDPLATE & CRATE
REMOVE SIDE PLATES FROM BED PLATE & CRATE
REMOVE BEDPLATE FROM YAW & PREPARE FOR SHIPMENT
RELEASE YAW MOUNTS & REMOVE SLIP RING/CRATE
FIT & SECURE FIXTURE TO YAW STRUCTURE
SHIP ALL COMPONENTS TO THE SITE

Figure 10-17 MOD-5A Factory and Component Disassembly

10.5.6.1 Yaw Subsystem Assembly

The purpose of the yaw subsystem is to position the wind turbine in azimuth, so that the rotor faces into the wind. The subsystem, shown in Figure 10-18, includes the horizontal thrust bearing and the hydraulic drive positioning system, all housed in a cylindrical structure. The subsystem is assembled in the factory and tested before shipment according to the following plan:

The upper rotating structure is attached to the bedplate in the field, and the lower, fixed structure interfaces with the tower. These two components are attached through the three-row, roller yaw bearing. The yaw drive actuators, brake calipers, hydraulic package and yaw slip ring are housed in the assembly. The assembly is 137 in. high, and 187 in. in diameter. It weighs 54,400 lbs., exclusive of the slip ring fixtures.

The yaw foundation assembly ring, a factory fixture shown in Figures 10-19 and 10-20, is used to support the yaw subsystem during assembly. The ring is installed on a suitable factory floor. The lower yaw structure is placed on the prepared foundation and secured with bolts and gusset plates. The yaw bearing is unpacked, degreased, placed on the lower yaw structure, and aligned with guide pins. The bearing is adjusted for parallelism and bolted at 72 points according to the torque specifications.

The upper yaw structure is prepared for mounting and the slip ring mounting beam flange is attached. The entire assembly is raised on a sling and the slip ring assembly is connected to the mounting flange. The subassembly is raised, then lowered onto the yaw bearing. Tapered guide pins are used to align the components. The assembly is bolted and tensioned to the proper preload. Parallelism and alignment are checked.

The drive subsystem components: the actuator support brackets, brake supports, brake units, guide assembly, track supports, track, and roller support brackets, are installed, followed by the hydraulic subsystem. This subsystem consists of a hydraulic module, valve blocks, a switch module, a

- TOWER INTERFACE WELDED
- BEDPLATE INTERFACE BOLTED
- YAW BEARING 3 ROW ROLLER BEARING (ROTEX)
- SELF CONTAINED UNIT FOR FACTORY TESTING

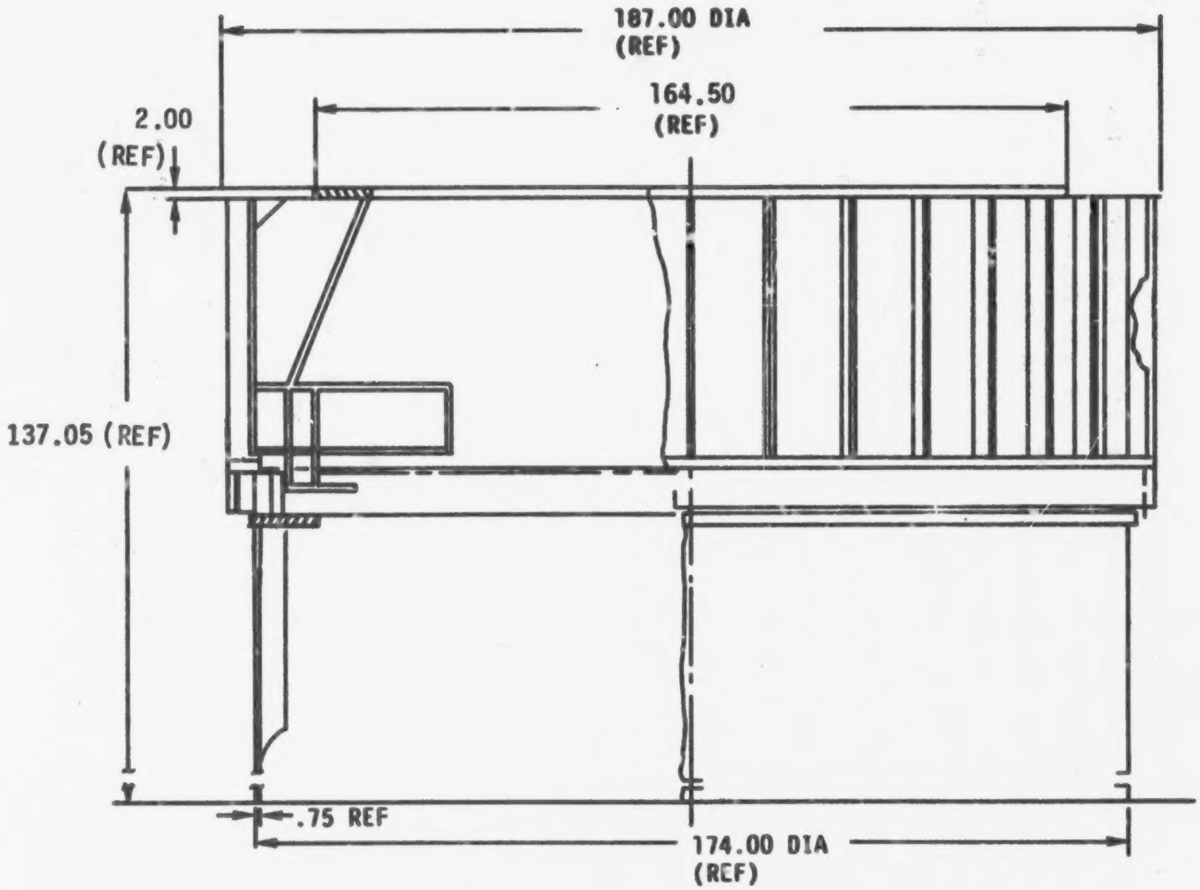
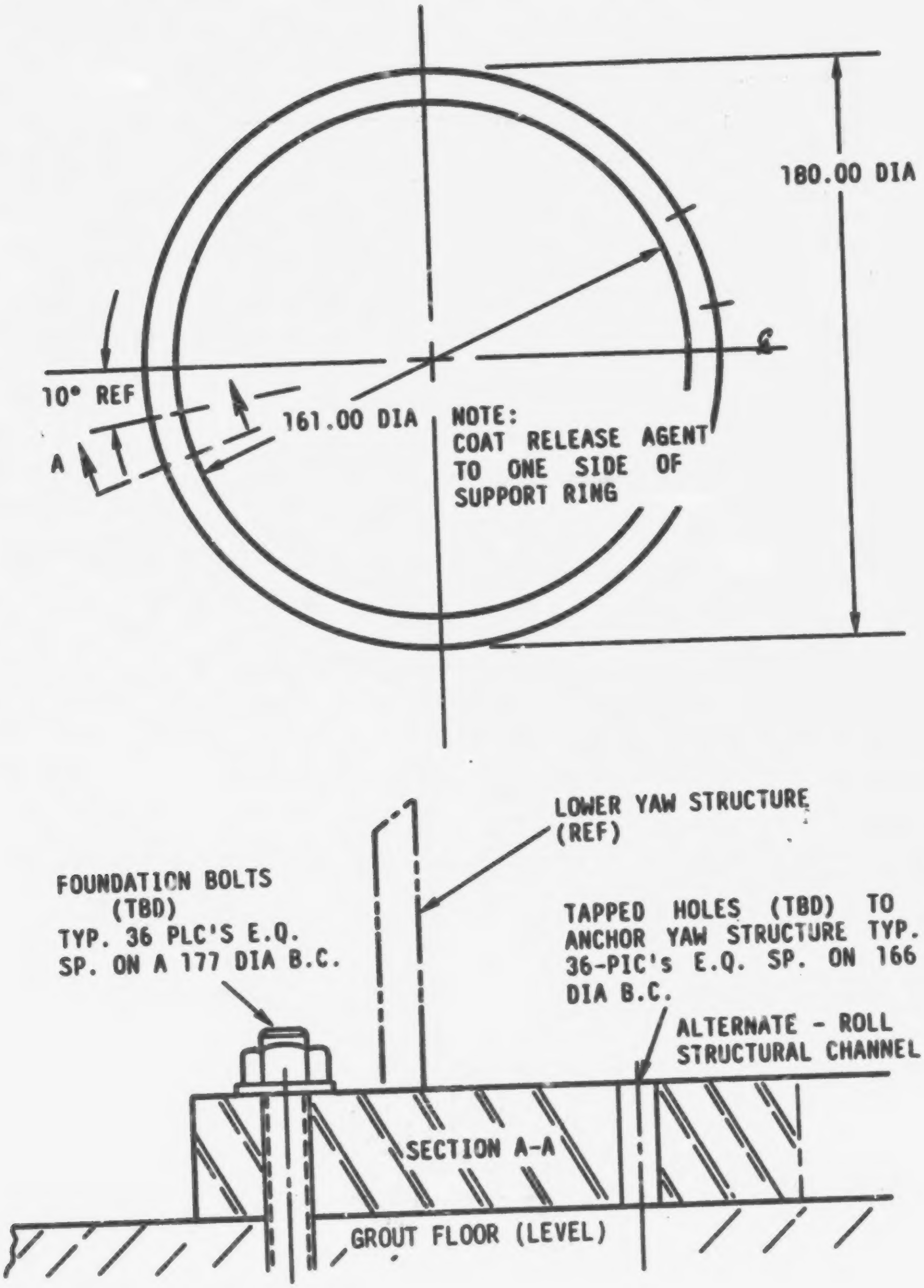

187.00 DIA (REF)
164.50 (REF)
2.00 (REF)
137.05 (REF)
.75 REF
174.00 DIA (REF)

Figure 10-18 Yaw Subsystem Structural Assembly


180.00 DIA
℄
10° REF
A
161.00 DIA
LOWER YAW STRUCTURE
(REF)
FOUNDATION BOLTS
(TBD)
TYP. 36 PLC'S E.Q.
SP. ON A 177 DIA B.C.
TAPPED HOLES (TBD) TO
ANCHOR YAW STRUCTURE TYP.
36-PIC's E.Q. SP. ON 166
DIA B.C.
ALTERNATE - ROLL
STRUCTURAL CHANNEL
SECTION A-A
GROUT FLOOR (LEVEL)

NOTE:
COAT RELEASE AGENT
TO ONE SIDE OF
SUPPORT RING

Figure 10-19 Yaw Structure Foundation Ring

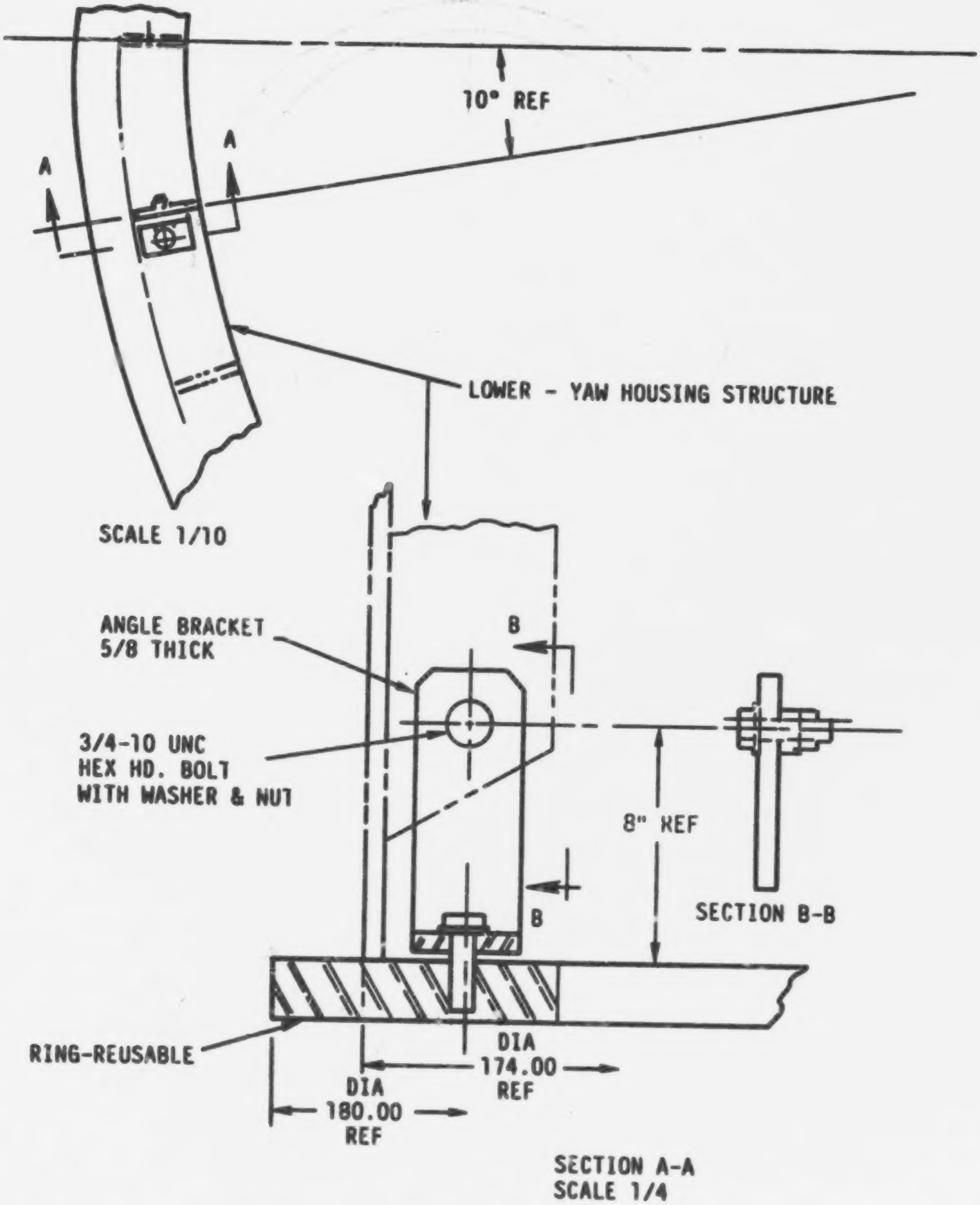

10° REF
A
A
LOWER - YAW HOUSING STRUCTURE
SCALE 1/10
ANGLE BRACKET
5/8 THICK
B
3/4-10 UNC
HEX HD. BOLT
WITH WASHER & NUT
8" REF
B
SECTION B-B
RING-REUSABLE
DIA
174.00
REF
DIA
180.00
REF
SECTION A-A
SCALE 1/4

Figure 10-20 Yaw Subsystem to Ring Attachment

filter, accumulator tanks and brackets, hydraulic lines, electrical connections, a position indicator, a weather shield, an accelerometer, an electrical construction, a slip ring shield, and other hardware. The yaw bearing breakaway torque is checked. The hydraulic system is flushed and filled, and the yaw drive subsystem is functionally tested. The slip ring is checked for continuity. The final inspection is performed, and the entire subassembly is prepared for shipping on a rail car or semitrailer.

10.5.6.2 Nacelle Subsystem Assembly

The nacelle consists of the bedplate, rotor adapter, side supports top covers, gearbox, generator, and mounting structures. The fairing, lube module and other miscellaneous components are included in the nacelle weight, for a total of approximately 145 tons.

The MOD-5A nacelle bedplate structure supports the rotor assembly through the gearbox structure, generator structure, electrical control cabinet, lube service module and fairing. The bedplate structure interfaces with the upper yaw structure. Sections of the integrated bedplate and rotor support structure are shown in Figure 10-21.

The assembly is described briefly in the following paragraphs. The nacelle components are accumulated in one area, ready for installation. The bedplate is lifted, positioned and bolted to the upper yaw assembly. The rotor adapter and generator support structures are lifted and attached in place on the bedplate.

The basic structure is completed by bolting the rotor adapter and the two side supports in place on the bedplate, using torque controlled wrenches. The lube service module is mounted in place on the bedplate. The flooring and three trap doors are installed.

The heavy mechanical components, gearbox and generator are lowered into position on their respective support structures and secured. Finally, the top cover area is completed by attaching the top cover forward structure, the aft structure, and top cover cross-section to the rotor adapter side supports.

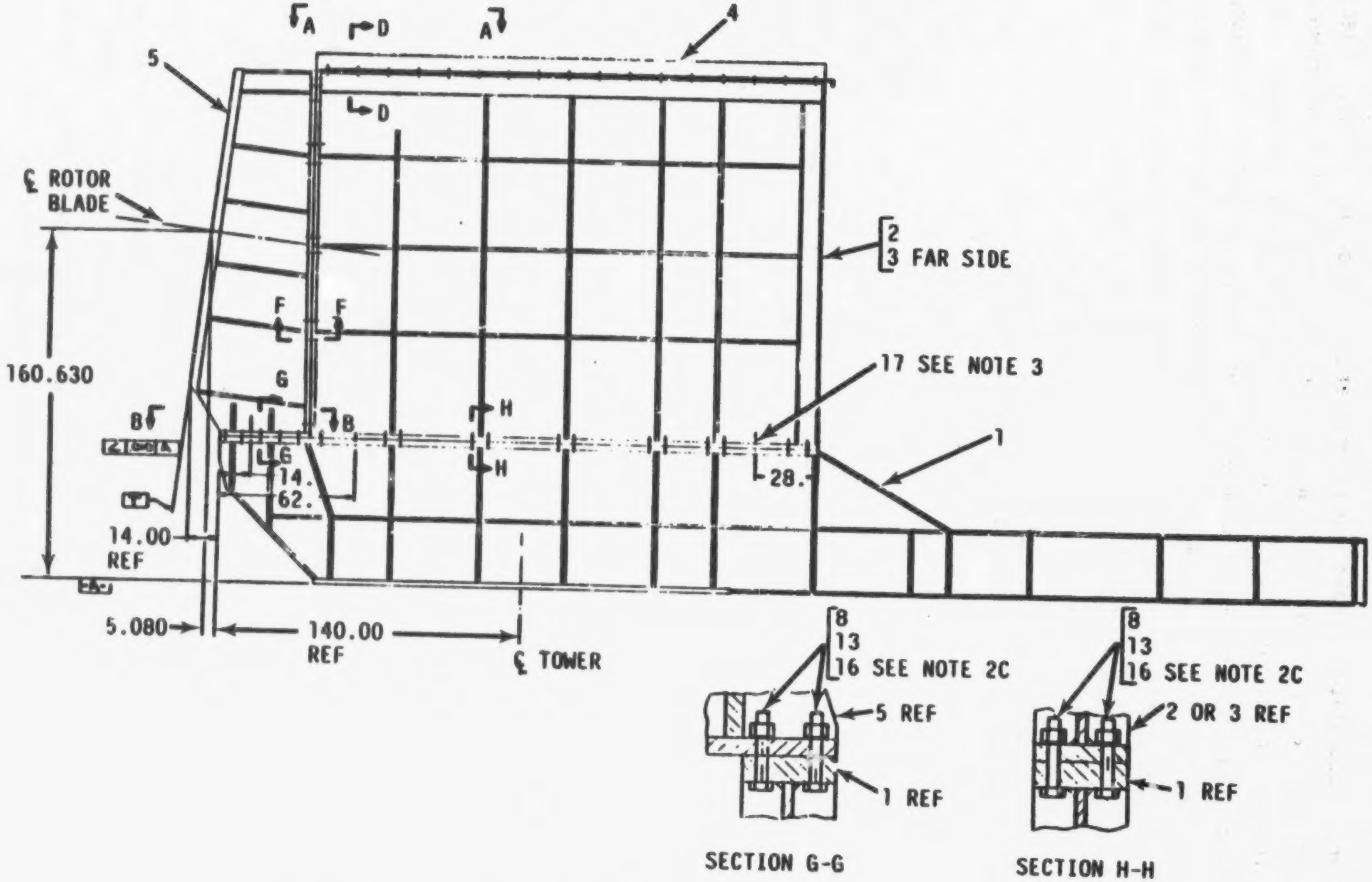

A
D
A
4
5
D
℄ ROTOR BLADE
2
3 FAR SIDE
F
F
160.630
G
17 SEE NOTE 3
B
B
H
1
G
H
14.
28.
62.
14.00 REF
5.080
140.00 REF
℄ TOWER
8
13
16 SEE NOTE 2C
5 REF
1 REF
SECTION G-G
8
13
16 SEE NOTE 2C
2 OR 3 REF
1 REF
SECTION H-H

Figure 10-21 Integrated Bedplate/Rotor Support Structure

10.5.6.3 Yoke and Spindle Assembly

The yoke and spindle assembly supports the blade and the spindle shaft is bolted to the rotor adapter structure. The assembly consists of seven major components; the yoke, forward and aft rotor bearings, spindle shaft, forward bearing retainer, torque plate and low speed brake disc. Sections of the yoke and spindle assembly are shown in Figure 10-22.

The yoke and spindle components are collected in one area, ready for installation. The yoke structure is positioned and secured on supports. The torque plate is oriented, clamped and matched drilled on the yoke center hub flange. After drilling, the torque plate is removed and temporarily set aside. The outer races are removed from the forward and aft rotor bearings leaving the roller and cage with the inner races. The outer races are fitted into the yoke bore. After the seal retainer ring is installed into the yoke housing, the inner race and roller set are installed onto the spindle shaft. The yoke assembly is lowered over the spindle shaft until the inboard rollers are in contact with the outer race. With the spindle shaft temporarily centered inside the yoke, the inner race and roller are placed into the yoke and spindle assembly until the rollers are in contact with the outer race. The forward bearing retainer plate is installed on the spindle shaft forward flange, and the yoke assembly is rotated about the bearing axis and checked for smooth running. The splined torque plate is aligned and bolted to the yoke center hub flange, and the yoke and spindle assembly are turned 180° so that the spindle shaft aft flange is up and the assembly rests on the torque plate. The seat retainer with the "O" ring is installed in the bearing housing, the low speed brake disc is installed on the yoke housing. The forward and aft seats and retainers are installed, the bearings are greased and the completed unit is ready to be lifted and bolted to the nacelle.

10.5.6.4 Electrical and Electronic Components

The controls and electronics cabinet contain a controller assembly, emergency shutdown panel signal conditioner, wind translator, switch test electronics and an ice detector. The cabinet is located in the nacelle along with a heat exchanger and air duct unit, as shown in Figure 10-16.

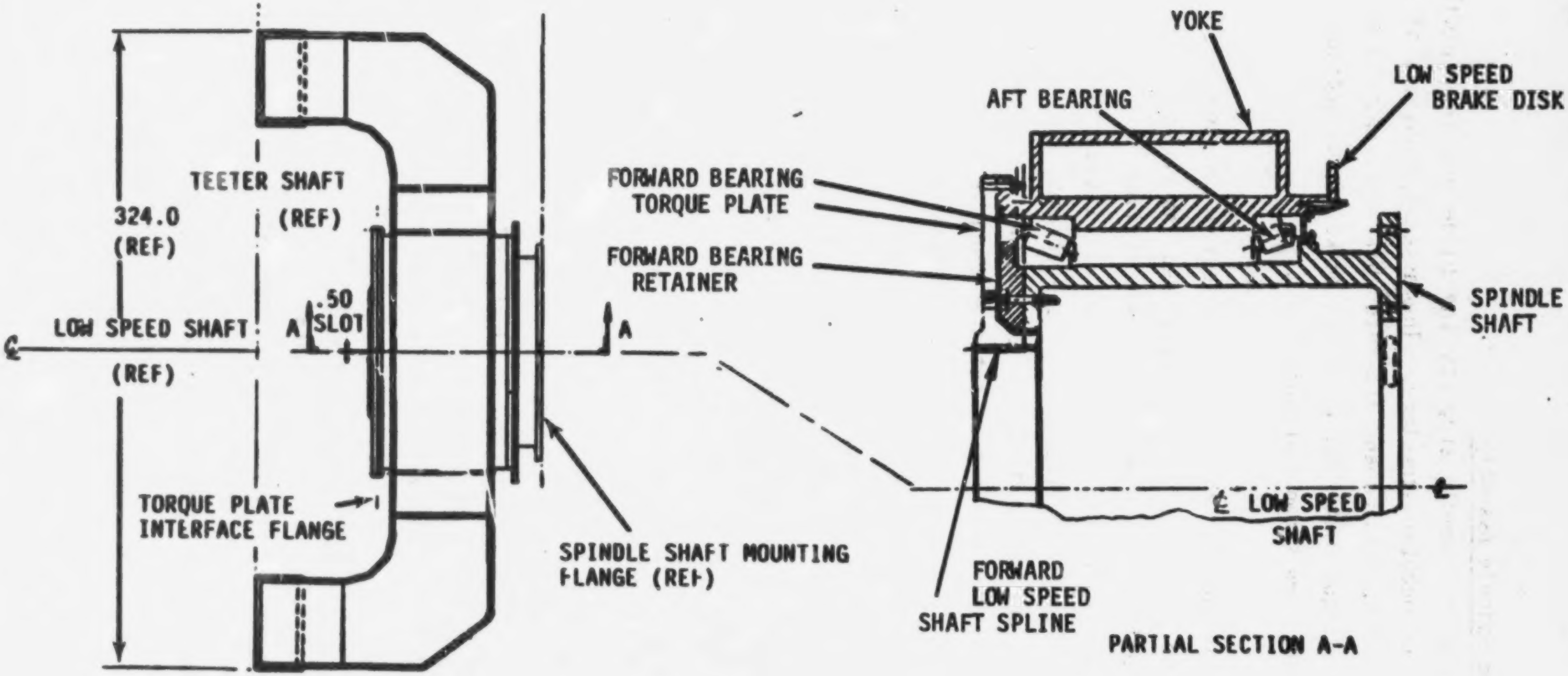

TEETER SHAFT
(REF)
324.0
(REF)
LOW SPEED SHAFT
(REF)
.50
SLOT
A
A
TORQUE PLATE
INTERFACE FLANGE
SPINDLE SHAFT MOUNTING
FLANGE (REF)
YOKE
AFT BEARING
LOW SPEED
BRAKE DISK
FORWARD BEARING
TORQUE PLATE
FORWARD BEARING
RETAINER
SPINDLE
SHAFT
℄ LOW SPEED
SHAFT
FORWARD
LOW SPEED
SHAFT SPLINE
PARTIAL SECTION A-A

Figure 10-22 Yoke and Spindle Assembly

After the controls electronics cabinet is bolted to the bedplate, the heat exchanger unit is attached to the cabinet. The air duct unit and enclosure, which ventilates the electronics cabinet, is connected to the heat exchanger and the nacelle fairing wall.

The high voltage cage contains a ground transformer, ground resistor, current transformers, potential transformers, and associated bus bars mounted in a protective enclosure. The high voltage cage is lifted and bolted onto the nacelle bedplate structure. Power cables are connected from the generator to the high voltage cage input junction electrical interface and between the high voltage electrical output junctions and yaw slip rings.

The video unit, intercom, multiplexer and sensors are also located in the nacelle. The video unit assembly is mounted on the nacelle fairing inside wall bracket. A similar installation involves an intercom unit, also mounted on the nacelle fairing inside wall. The nacelle multiplexer cabinet is assembled and inspected, then lifted and bolted to the nacelle bedplate structure. Various sensors are mounted throughout the nacelle, rotor, yaw structures and drive components. After all the electrical and electronic components are installed, they are wired to the junction boxes and panels and inspected.

10.5.6.5 Other Hardware Factory Assembly

This category includes: connecting the drivetrain, attaching the yoke hydraulics, fitting the yoke teeter restriction assemblies, installing the yoke and spindle shaft assembly, mounting the low speed brake assembly, inspecting the fit of the elastomeric teeter shaft bearings and the installation of the fairing and service platforms attached to the bedplate structure.

The low speed shaft and couplings are engaged to the torque plate and gearbox splines to connect the drivetrain. The high speed shaft couplings connect the gearbox to the generator.

The teeter shaft bearings are built up from two elastomeric bearing assemblies. A radial bearing, sleeve and thrust bearing are inserted into a hub. A bearing assembly is placed on each end of the teeter shaft.

The sequence for installing each of the auxiliary components follows: after accumulating the low speed shaft components, the forward and aft splined couplings are fitted to the low speed shaft. The low speed shaft assembly is fitted to the yoke and spindle torque plate splines and secured. Temporary spacer adjustable support fixtures are attached between the spindle and low speed shaft. During a dial indicating operation, the fixtures are adjusted to maintain a correct tolerance between the spindle and low speed shaft aft coupling.

After the subassembly is complete, the hydraulic package, is installed on the yoke and spindle assembly. Four teeter restrictor subassemblies are completed and mounted on the yoke. The yoke and spindle assembly, with the low speed shaft coupling securely engaging the torque slot splines, is lifted and the aft coupling splines are started into the gearbox splines. The gearbox splines are rotated to the proper alignment. The low speed shaft support fixtures are removed after the spindle and rotor adapter attachment studs are installed.

The low speed brake frame assemblies are mounted to the rotor adapter structure face plate and the stationary brakes are aligned on the rotating yoke center hub brake disc. The high speed shaft coupling is connected to the gearbox stub shaft coupling. The generator base plate is shimmed to align the high speed shaft and generator shaft couplings.

The fairing component base channels are clamped to the bedplate structure, side supports and top cover aft structure, and matched drilled. After the fairing base channels are bolted to the bedplate, side supports and top cover aft structures, the remaining fairing panels and supports are assembled. Later the fairing structure panels are modified to accept the exhaust ductwork. Service platforms and safety trails are bolted to the bedplate structure sides and front.

Teeter bearing assemblies are mounted on each end of the teeter shafts and secured with a ring-feeder clamp. The teeter shaft assembly is raised and positioned and the yoke bearing caps are mounted to secure the teeter shaft assembly to the yoke. The drivetrain is tested by motoring the generator.

10.6 SHIPPING PLAN

The MOD-5A wind turbine generator subsystems, components, fixtures, and tools, will be shipped from GE or the subcontractor to a site near Kahuku, Oahu, HI. This site was identified for the first MOD-5A installation. The following plan is specifically for the Kahuku site, rather than the generic site in Cleveland, OH.

Most of the subsystems and components will be shipped to an assembly area near King of Prussia, PA. There, subsystems and components will be fitted, assembled and tested. The assemblies will be divided into modules, which will be shipped to a staging area on the west coast, in Portland, OR or Oakland, CA. The modules will be loaded on ocean barges and shipped to Honolulu, HI.

Subsystems and components that are not available or are not required for fitting, assembly, and testing in the factory will be shipped to Honolulu, HI or to the staging area on the west coast. All shipments will be received at Honolulu, and will be stored in rented space on the docks or transported immediately to the site.

The shipment of subsystems and components from GE, or from a subcontractor, to the assembly plant in King of Prussia is the supplier's responsibility. If the subsystems or components are not required for factory fitting, assembly, and test, the supplier will ship the equipment to the staging area on the west coast or to the wind turbine generator site. Before shipment, the supplier's transportation plan must be submitted to the GE-AEPD Traffic operation for approval. Each plan will be considered and the shipping method providing the best combination of cost, schedule, and safety will be selected.

Three shipping modes take into account the location of the supplier and the assembly location, the size and weight of the material, the transit time and the shipping cost. The modes are truck, rail, and ocean as follows:

Truck for shipping between the:
- Supplier and the assembly plant
- Supplier and the dock
- Assembly plant and the railroad
- Assembly plant and the dock
- Dock and the wind turbine generator site

Rail for shipping between the:
- Supplier and the assembly plant
- Supplier and the dock
- Assembly plant and the dock

The characteristics of a standard load for each shipping mode are listed below:

Truck
- 8 ft. wide, 13.5 ft. high, including trailer height
- Standard flat bed trailer height: 4 ft., 6 in.
- Low boy trailer height: 1.5 ft, to 3 ft.
- Net weight: 42,000 to 45,000 lbs.
- Gross vehicle weight: 74,000 to 77,000 lbs.
- Trailer length: 40 ft. to 45 ft.
- Low boy trailer well: 22 ft. to 28 ft. long

Rail
- 12.5 ft. wide at 7 ft. above the rail (ATR)
- 18 ft., 2 in. high, including the rail car
- 40 ft. to 89 ft. long standard cushioned flat car
- 200,000 lbs. net weight
- Standard rail shipments generally accommodate much larger pieces of equipment than trucks can accommodate

Ocean
- All MOD-5 equipment can be transported via standard ocean vessels

The requirements for non-standard loads are:

Truck loads requiring permits and special routing:
- Width: 12 ft.
- Height: 13.5 ft. to 14 ft, 2 in., including the trailer
- Length: 100 ft.
- Net weight: 70,000 to 80,000 lbs.

The cost for such a load is 50% to 70% above the cost of a standard load.

Truck loads requiring escorts, permits and special routing:
- Width: 14 to 18 ft.
- Height: 14 to 16 ft., including the trailer
- Length: over 100 ft., including the tractor and trailer
- Weight: 200,000 lbs. gross, requires extra wheels

The cost for such a load is 200% to 300% above the cost of a standard load.

Rail loads requiring special routing:
  Width: 12 to 13 ft.
  Height: 18 ft, 2 in. to 19 ft. above the rail
  Length: 100 to 125 ft.

The costs for such a load are 25% to 50% above the standard costs and the transit time is approximately doubled.

Rail loads requiring special trains and routing:
  Width: 13 to 14 ft.
  Length: 19 to 20 ft. above the rail

The costs for such a load are 300% to 500% above the standard costs.

The approximate costs in 1983 dollars for standard shipments are listed below:
  Truck: 14¢ per ton, per mile
  Rail: 13¢ per ton, per mile, plus the loading site cost
  Ocean: 7¢ per pound, between the west coast and Hawaii

The component supplier, or a fixture vendor, provides fixtures for all shipping and handling. Blade fixtures are used both for handling the blade in transit and for use at the site. Yoke, gearbox, bedplate and generator fixtures are used for shipping between the assembly plant and the site.

Table 10-7 lists the sizes and weights of the major components of the wind turbine generator. The table indicates the origin, destination and shipping mode for each subsystem or component.

Table 10-7. Subsystem Sizes and Weights

SUBSYSTEM	SIZE	WEIGHT (LBS)	FIXTURE WEIGHT (LBS) CUSTOM (C) STANDARD (S)	NOTES SEE END OF TABLE	MODE
YAW	12' high, 16' across	54,400	5,400 (S)	2, 4	TRUCK - 3 AXLE - LOW BOY
BEDPLATE	44' x 14' x 8'	94,000	13,000 (C)	2, 4	RAIL - GONDOLA
ROTOR ADAPTER					
FRONT SUPPORT	14' x 14' x 4'9"	56,800	5,000 (S)	2, 4	RAIL - GONDOLA
SIDE SUPPORT (2)	16'6" x 14' x 9'	20,470 each	3,250 (S)	2, 4	RAIL - GONDOLA
TOP COVERS (3)	19'7" x 14' x 7'7"	18,870	1,000 (S)	2, 4	RAIL - GONDOLA
GEARBOX:	17' x 10' x 12'	140,000	13,700 (C)	2, 4	RAIL - WELLCAR
GENERATOR	14' x 8'4" x 7'4"	46,000	4,600 (C)	4	TRUCK-AIR-RIDE -LOW BOY
HIGH SPEED SHAFT & COUPLINGS	4' x 3'4" diameter	3,000	300 (S)	2, 4	TRUCK-STAND. -AIR-RIDE
ROTOR SLIP RING ASSEMBLY	5' x 1' x 2'	500	50 (S)	2, 4	" "
HIGH VOLTAGE CAGE	3' x 9' x 2'	2,000	200 (S)	2	" "

Table 10-7. Subsystem Sizes and Weights

SUBSYSTEM	SIZE	WEIGHT (LBS)	FIXTURE WEIGHT	NOTES	MODE
CONTROLS ENCLOSURE	4' x 6' x 2'	2,000	20 (S)	2	" "
LUBE, MODULE	6' x 2' x 6'	6,100	600 (S)	2, 4	TRUCK-STAND. -AIR-RIDE
FAIRING (DISASSEMBLED)	15'4" x 8' x 4'	8,800	800 (S)	2, 4	TRUCK-STAND. -AIR-RIDE
YOKE ASSEMBLY	25'6" x 12' x 12'	150,000	15,000 (C)	2, 4	RAIL-CUSHION FLAT CAR
SPINDLE SHAFT	7' x 8' diameter	30,000	3,000 (S)	2	TRUCK-STAND. -AIR-RIDE
LOW SPEED SHAFT ASSY	12' x 5' diameter	66,700	6,700 (S)	2, 4	RAIL-CUSHION FLAT CAR
ROTOR BEARINGS (2)	9'2" diameter x 2'	8,000	800 (S)	2	TRUCK-STAND. -AIR-RIDE

Table 10-7. Subsystem Sizes and Weights

SUBSYSTEM	SIZE	WEIGHT (LBS)	FIXTURE WEIGHT	NOTES	MODE
TEETER BEARINGS (2) RADIAL	15' x 4' diameter	3,000 each	500 (S)	2, 4	TRUCK-STAND. -AIR-RIDE
TEETER BEARINGS (2) THRUST	14' x 3' diameter	2,000 each	400 (S)	2, 4	TRUCK-STAND. -AIR RIDE
CENTER BLADE	100' x 15' x 8'	128,000	10,800 (C)	5	RAIL-89' CUSHION FLAT CAR WITH TWO 2 IDLER CARS
INNER BLADES (2)	70' x 15' x 8'	39,500 each	6,500 (C)	5	RAIL-89' FLAT CAR
OUTER BLADES (2)	80' x 12' x 3'	12,500 each	3,100 (C)	5	RAIL-89' CUSHION FLAT CAR
TRAILING EDGES, 2 SETS	30' x 10' x 7'	650 each		5	TRUCK STD. AIR-RIDE
" "	35' x 10' x 7'	590 each	500 (S)	5	
" "	35' x 8' x 3'	360 each		5	

Table 10-7. Subsystem Sizes and Weights

SUBSYSTEM	SIZE	WEIGHT (LBS)	FIXTURE WEIGHT	NOTES	MODE
AILERON SETS (2 SETS)	25' x 5' x 3'	4,760	1,000 (S)	3, 5	TRUCK STD. AIR-RIDE
BOLSTERS (2)	25' x 8' x 2'	15,000 each	3,000 (S)	5	TRUCK STD. AIR-RIDE
ISOL. XFMR	6' x 5' x 9'	12,000	1,200 (S)	2, 4	TRUCK STD. AIR-RIDE
SWITCH GEAR ASSY	10' x 8'4" x 8'4"	14,000	1,400 (S)	2, 4	TRUCK STD. AIR-RIDE
CYCLO CONVERTER	15' x 7' x 7'6"	9,000	900 (S)	2, 4	TRUCK STD. AIR-RIDE
UNINTERRUPTED POWER SUPPLY	8' x 3' x 3'	2,000	200 (S)	1	" "
BATTERY	5' x 7' x 3'6"	1,200	100 (S)	1	" "
STEP-UP XFMR	7' x 7' x 10'	5,000	500 (S)	2, 4	" "

Table 10-7. Subsystem Sizes and Weights

SUBSYSTEM	SIZE	WEIGHT (LBS)	FIXTURE WEIGHT	NOTES	MODE
AUX. XFMR	8' x 7' x 6'	5,000	500 (S)	2, 4	TRUCK-STAND.
HARMONIC FILTER	6' x 5' x 9'	6,000	600 (S)	2, 4	" "
POWER CABLING	6300', 350 MCM	10,000	500 (S)	1	" "
ELEVATOR STRUCTURE	30' x 5' x 5'	12,000	1,000 (S)	2, 4	" "
ELEVATOR	8' x 4' x 4'	2,000	100 (S)	1	" "

The notes refer to the following shipping plans:

1. Ship from the supplier to the staging area on the west coast or Honolulu, HA.
2. Ship from the supplier to the assembly plant in King of Prussia, PA, for fitting, assembly, and testing.
3. Ship from the supplier to Bay City, MI for the blade assembly.
4. Ship from the assembly plant in King of Prussia, PA to the staging area on the west coast or Honolulu, HA.
5. Ship from Bay City, MI to the wind turbine generator site in Hawaii.

10.7 WIND TURBINE GENERATOR ASSEMBLY AT SITE

This section describes the assembly operations, which are discussed further in section 11, Site and Erection.

Following the erection of the tower, the yaw subsystem is functionally checked, raised, and welded to the tower. The bedplate subassembly is placed on cribbing in the correct position for hoisting and installation on the yaw subsystem and the nacelle assembly is completed. When the assembly is complete, the bedplate is lifted and bolted to the yaw subsystem. The following subsystems are lifted and installed; gearbox, yoke and spindle shaft assembly with the low speed shaft engaged, the rotor adapter top covers, high speed shaft, electrical cabinets, duct work, fairing, maintenance crane and platforms. The blade will have arrived at the site, along with the trailing edges, bolsters, teeter hardware, ailerons, fixtures and supplies. After the nacelle is erected, the rotor will be assembled on a long, flat, prepared area near the tower. After proof testing, the rotor is erected and installed to the yoke to complete the assembly operation.

10.7.1 TOWER ERECTION

Tower components are fabricated in sections and shipped to the site as described in section 10.5.4. At the site, subassemblies are fitted and welded into full circular sections on the ground. The base ring is fitted, welded, positioned and bolted to the foundation. The long transition sections are fitted to the base ring and to each other, welded together and inspected. A knuckle section is fitted and welded to the top of the transition section, and then it is inspected. The long cylindrical sections of the tower are fitted, welded and inspected on the ground, then hoisted and welded to the transition section. This operation is repeated until all sections are erected.

The elevator structure will be erected with the tower. Platforms will be installed at the required locations. The elevator structure and platforms will support the work platforms required for tower and elevator structure erection. After the tower and elevator structure are erected, the elevator will be installed by the elevator subcontractor.

10.7.2 BLADE ASSEMBLY AND ERECTION AT SITE

The laminated wood blade arrives at the site in five sections, along with the trailing edges, bolsters, teeter shaft, bearings and ailerons. Besides the components of the blade assembly, there is an array of fixtures, bunks, cribbing, track, epoxy materials, supplies, lifting apparatus and a rail-mounted, portable building required to join the blade. The stages of blade assembly are shown in Figures 10-23 through 10-27.

The sequence of operations for the field site blade assembly is as follows: The site is leveled and prepared with blade-leveling equipment, including bunks, fixtures, cribbing material, portable building, and supplies.

The center blade is secured by two rotating ring devices, then leveled, using optical equipment, and fastened to bunk supports. The bolsters are applied on both sides, rotating the center blade as required, to bond the epoxy joints in the controlled environment in the rail-mounted portable building. The teeter shaft, and teeter bearing caps are assembled at the same station, rotating the blade to ensure proper distribution of the epoxy in these joints. The center blade is then rotated 90°, so that the teeter shaft is horizontal, in preparation for the finger joint assembly of each inboard blade section.

The portable building is relocated over one of the inboard blade finger joints. The inboard blade is lifted onto bunks, leveled, and aligned optically with the center blade. The finger joint protective covers are removed and a trial dry fit is made. Optical realignment proceeds until the fit is satisfactory. The epoxy is then applied according to process specifications, and the joints squeezed and wrapped. The inner spar shear plate reinforcements are added. The lightning protection circuit, electrical and hydraulic lines, required ballasting, and hardware are then applied. The portable building is relocated to the next inboard joint section, and the same operations repeated on this and the outboard blades, until the main blade structure is completely assembled.

The blade assembly is finished by adding the trailing edges, the ice detectors, ailerons (including fitting and testing articulation) and connecting the hydraulic and electrical lines. The exterior blade surface is

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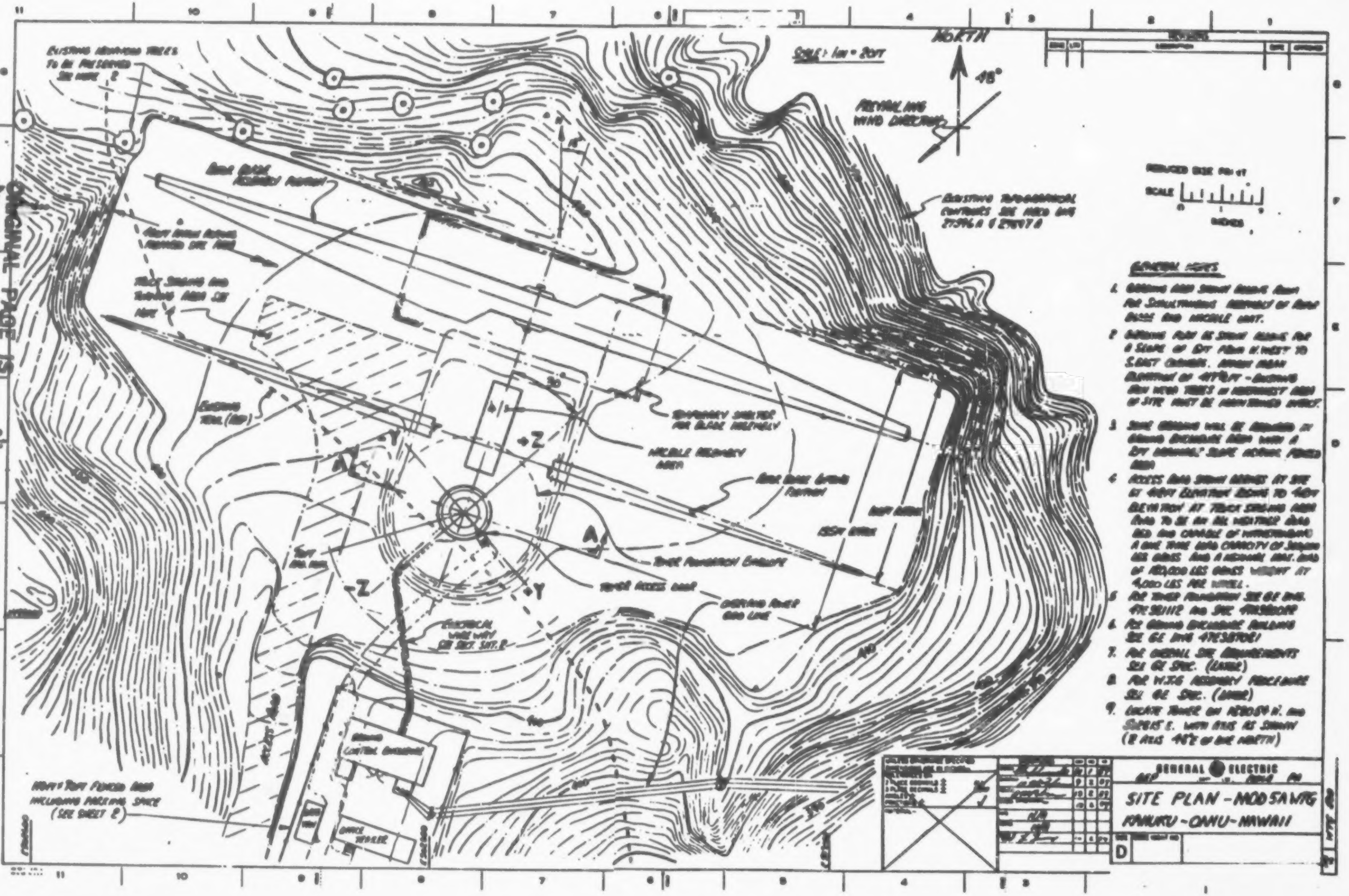
NORTH
48°
PREVAILING WIND DIRECTION
SCALE: 1in = 20FT
REDUCED SIZE
SCALE
INCHES
EXISTING TOPOGRAPHICAL CONTOURS
GENERAL NOTES
+Z
-Z
+Y
-Y
GENERAL ELECTRIC
SITE PLAN - MOD 5A WTG
KAHUKU - OAHU - HAWAII
D

Figure 10-23 Blade Assembly at the Site

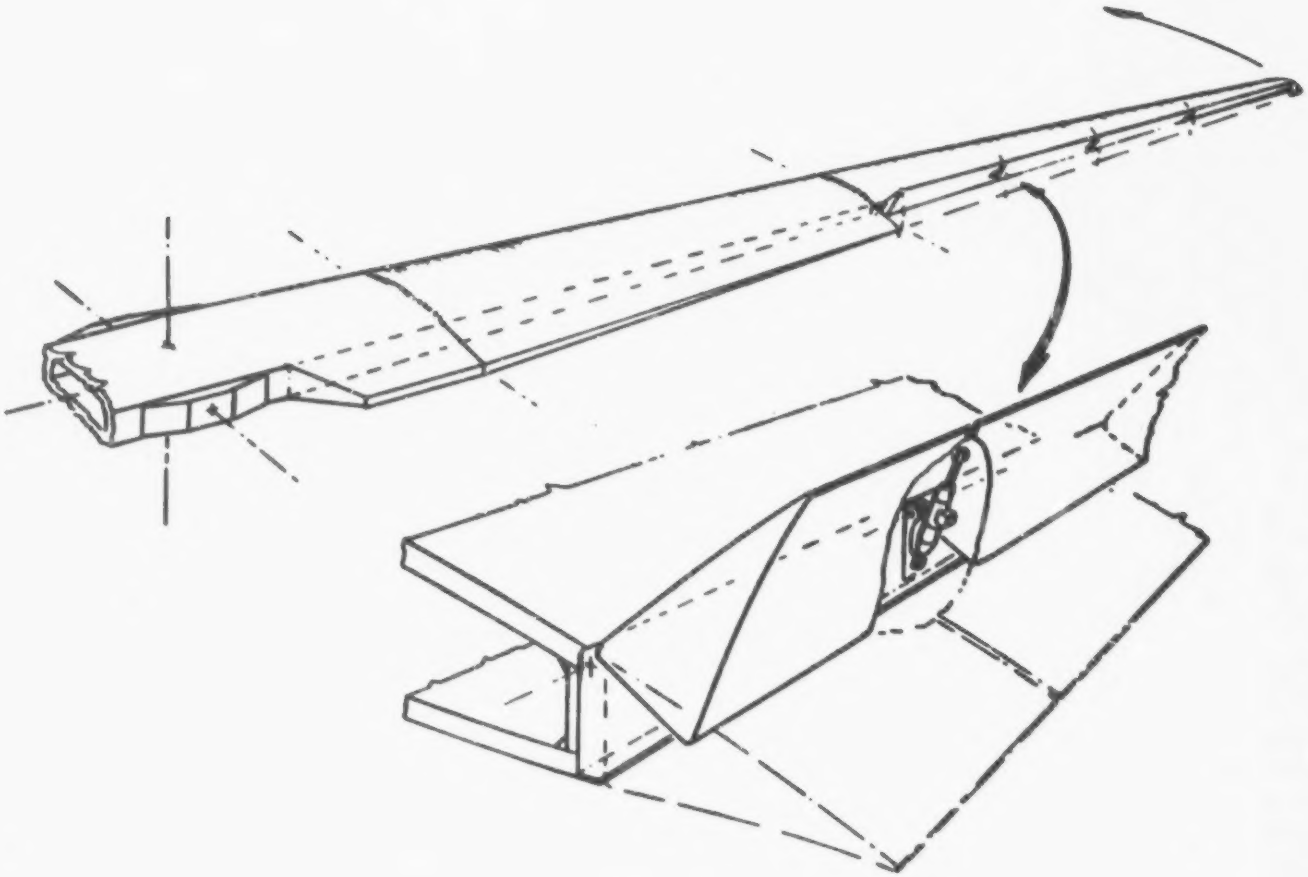

Figure 10-24 Aileron Assembly

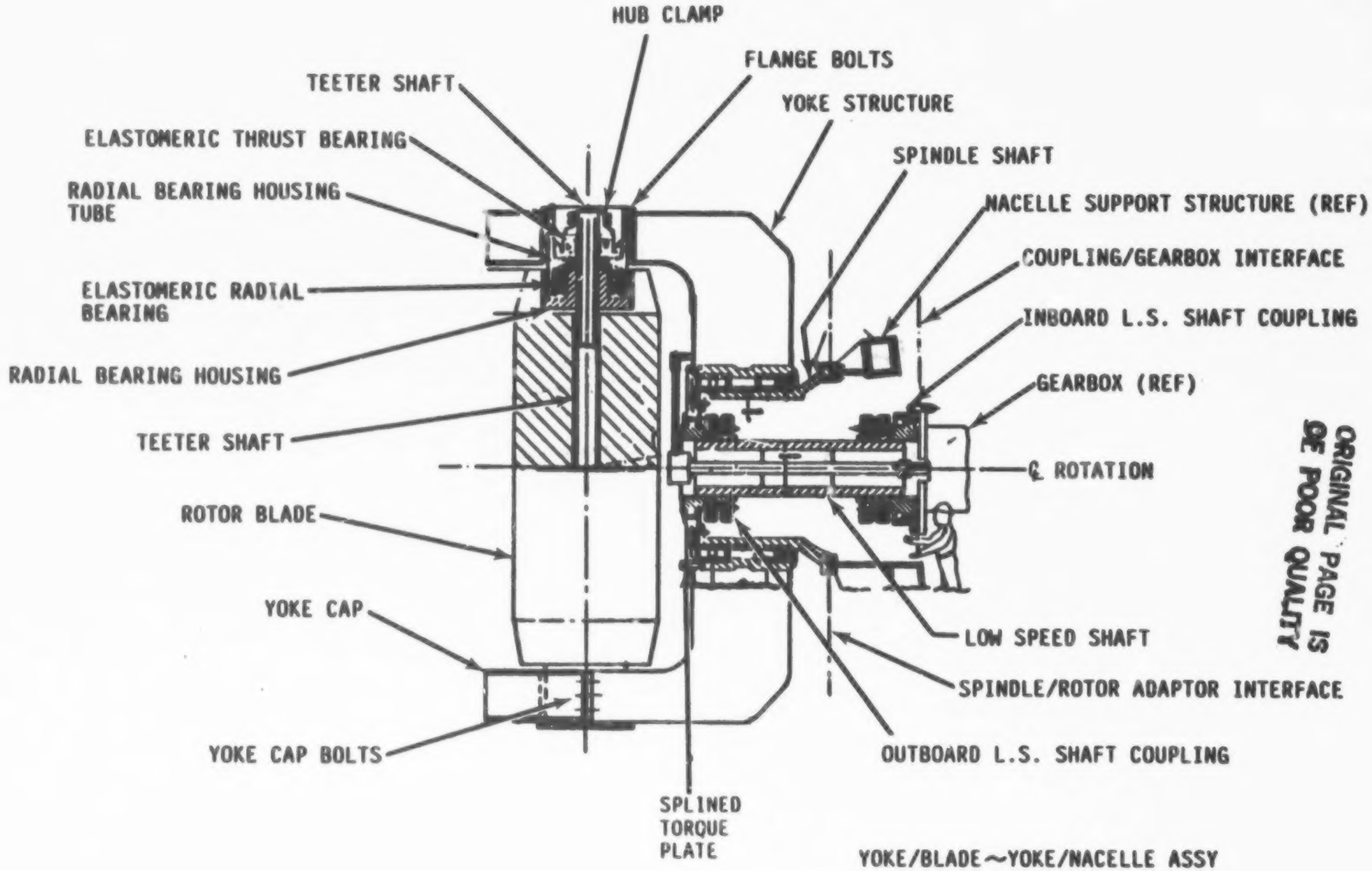
HUB CLAMP
FLANGE BOLTS
TEETER SHAFT
YOKE STRUCTURE
ELASTOMERIC THRUST BEARING
SPINDLE SHAFT
RADIAL BEARING HOUSING TUBE
NACELLE SUPPORT STRUCTURE (REF)
COUPLING/GEARBOX INTERFACE
ELASTOMERIC RADIAL BEARING
INBOARD L.S. SHAFT COUPLING
RADIAL BEARING HOUSING
GEARBOX (REF)
TEETER SHAFT
℄ ROTATION
ROTOR BLADE
YOKE CAP
LOW SPEED SHAFT
SPINDLE/ROTOR ADAPTOR INTERFACE
YOKE CAP BOLTS
OUTBOARD L.S. SHAFT COUPLING
SPLINED TORQUE PLATE
YOKE/BLADE~YOKE/NACELLE ASSY

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Figure 10-25 Teeter Assembly

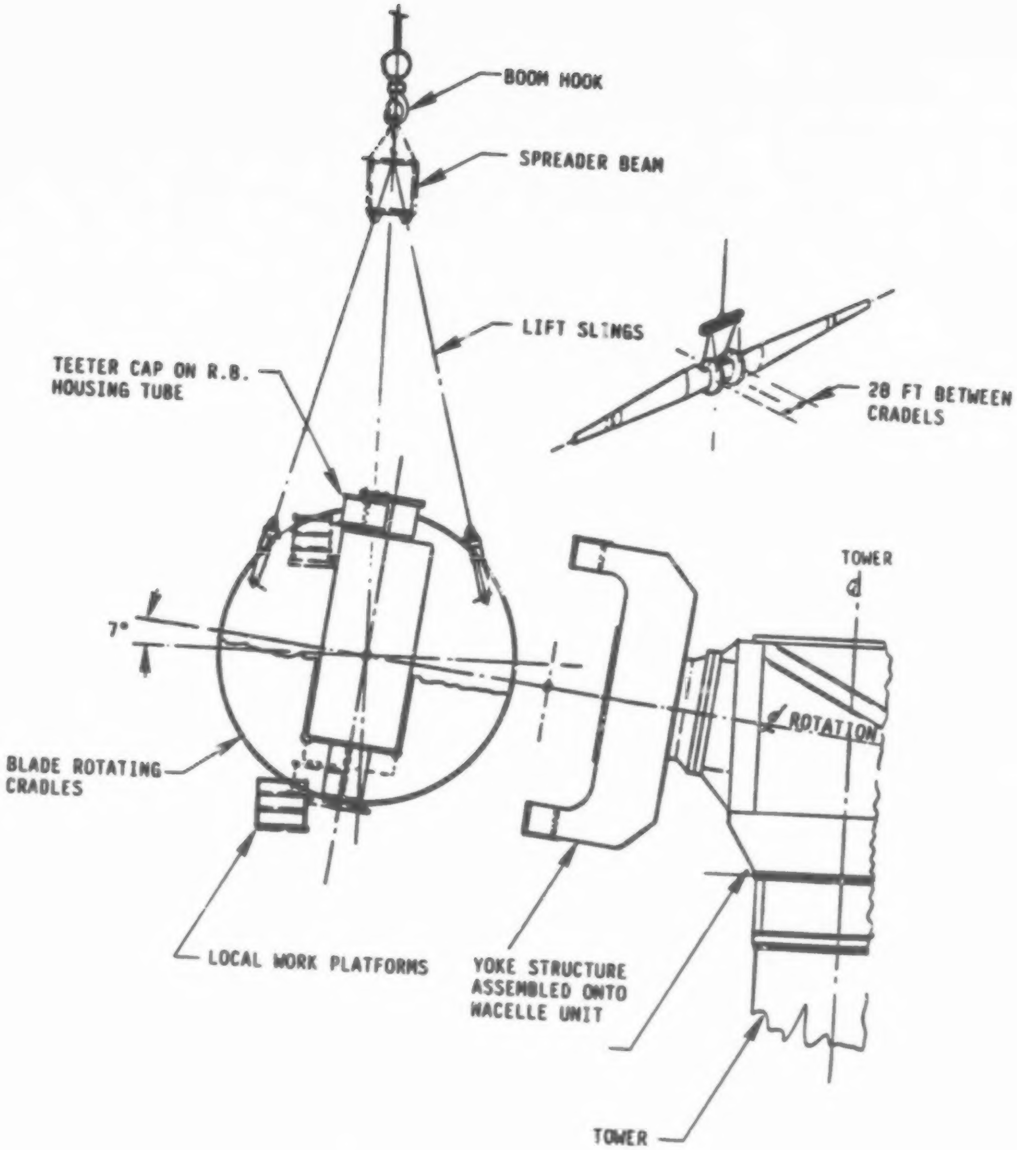
BOOM HOOK
SPREADER BEAM
LIFT SLINGS
TEETER CAP ON R.B. HOUSING TUBE
28 FT BETWEEN CRADELS
TOWER ℄
7°
℄ ROTATION
BLADE ROTATING CRADLES
LOCAL WORK PLATFORMS
YOKE STRUCTURE ASSEMBLED ONTO NACELLE UNIT
TOWER

Figure 10-26 Blade Installation in the Field

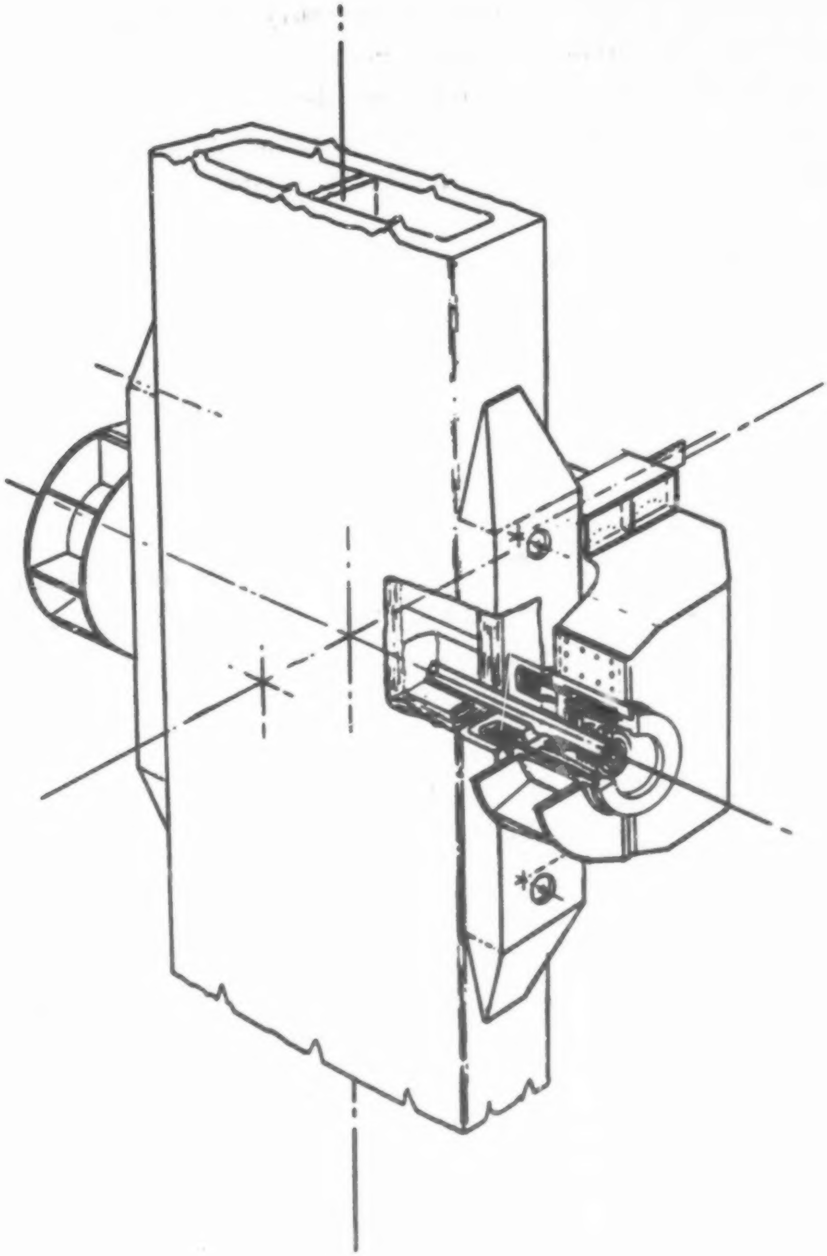

Figure 10-27 Blade, Bolster, and Yoke Assembly

finished at the joint areas with epoxy paint. The outer blade tips are attached, and the entire blade is balanced.

When the tower structure, yaw and nacelle assembly described later in this report are completed, the following blade erection procedure will begin. The blade is lifted with a turnover fixturing device. Blade deflection is measured, the entire blade is rotated 180° and the deflection is measured again. The bearing caps are applied to the teeter shaft.

The blade is then raised and tilted to 83° (to match the 7° yoke tilt). The teeter shaft is placed in the yoke sockets, and the yoke bearing caps are secured in place. The electric and hydraulic lines, and restrictor arms are connected. The safety platforms and rigging materials are removed, and the blade rotation is tested.

10.7.3 Nacelle and Yaw Field Assembly

The yaw subsystem assembly is prepared and hoisted as a unit to the top of the tower structure. A rigging counterweight fixture will be utilized to keep the yaw upright during the hoist operations. The yaw assembly is welded to the top of the tower.

The bedplate assembly is set up on cribbing at the tower base. The bedplate is secured to the cribbing in the correct attitude for erection and assembly to the yaw subsystem, and the rotor adapter and side supports are installed on the bedplate. The generator is installed on the mounting structure and the lubrication module is attached on the underside of the bedplate. The lift bars are attached to the bedplate and the spreader frame is hooked on the crane and lift bars. The nacelle assembly, as shown in Figure 10-28, without the gearbox, is lifted and bolted to the yaw structure.

10.7.4 Yoke and Gearbox Assembly

After the nacelle is lifted and bolted to the yaw structure, the gearbox is raised and installed to the gearbox mounting structure. Next, three top covers, the forward and aft sections and the cross-section are hoisted and fastened to the rotor adapter structure and side supports. The platforms, walkways and ladders are lifted to the bedplate structure and installed. The yoke, spindle and torque plate assembly with the low speed shaft coupling

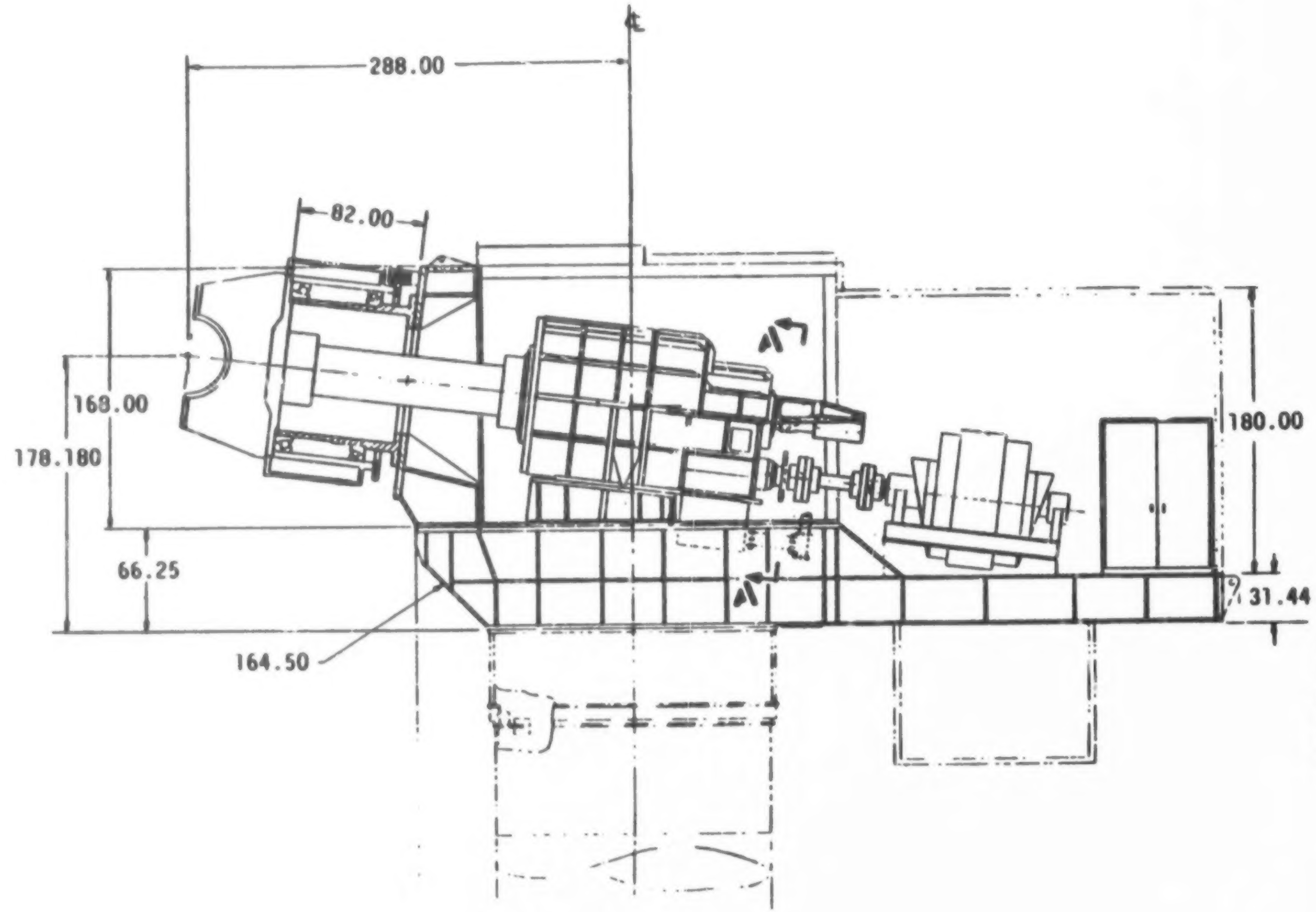
288.00
82.00
168.00
178.180
66.25
164.50
180.00
31.44

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Figure 10-28 Nacelle and Yaw Field Assembly

splines engaged, centered and secured inside the spindle shaft, are hoisted at the 7° tilt angle. The studs that attach the spindle to the rotor adapter are installed and tensioned. Finally, the adjustable support fixtures are removed from the low speed shaft. The final configuration is shown in Figure 10-29.

10.7.5 Other Component Field Assembly

In this part of the field assembly the installation of the low speed brake system is completed, the high speed shaft assembly between the gearbox and generator is aligned and connected, and the fairing is attached to the bedplate, rotor adapter, side supports and top cover. When these components are secured, the hydraulic couplings are connected.

The low speed brakes are installed on the spindle shaft brake disc and secured to the segmented rotor adapter structure brackets. The high speed shaft is lifted and installed, connecting the coupling end to the gearbox stub shaft coupling. The generator base structure is shimmed to align the generator stub shaft coupling with the high speed shaft coupling. The generator base structure is secured to the support structure.

The fairing is lifted, positioned and secured to the bedplate, side supports and top cover aft structure. Finally, all hydraulic couplings are connected.

10.7.6 Electrical Component Assembly

After the electrical equipment building is constructed, and the cable trenches between the tower and the electrical equipment building are covered with gratings, the controls electronics cabinet is lifted and secured to the bedplate. The heat exchanger, air duct and enclosure are installed. The high-voltage cage is hoisted and bolted to the bedplate, and power cables are connected between the generator, high voltage cage and yaw sliprings. The fairing is installed, and the video unit and intercom are mounted on the nacelle fairing wall. The nacelle multiplexer is raised and fastened to the bedplate, and all electrical terminals and junctions are connected.

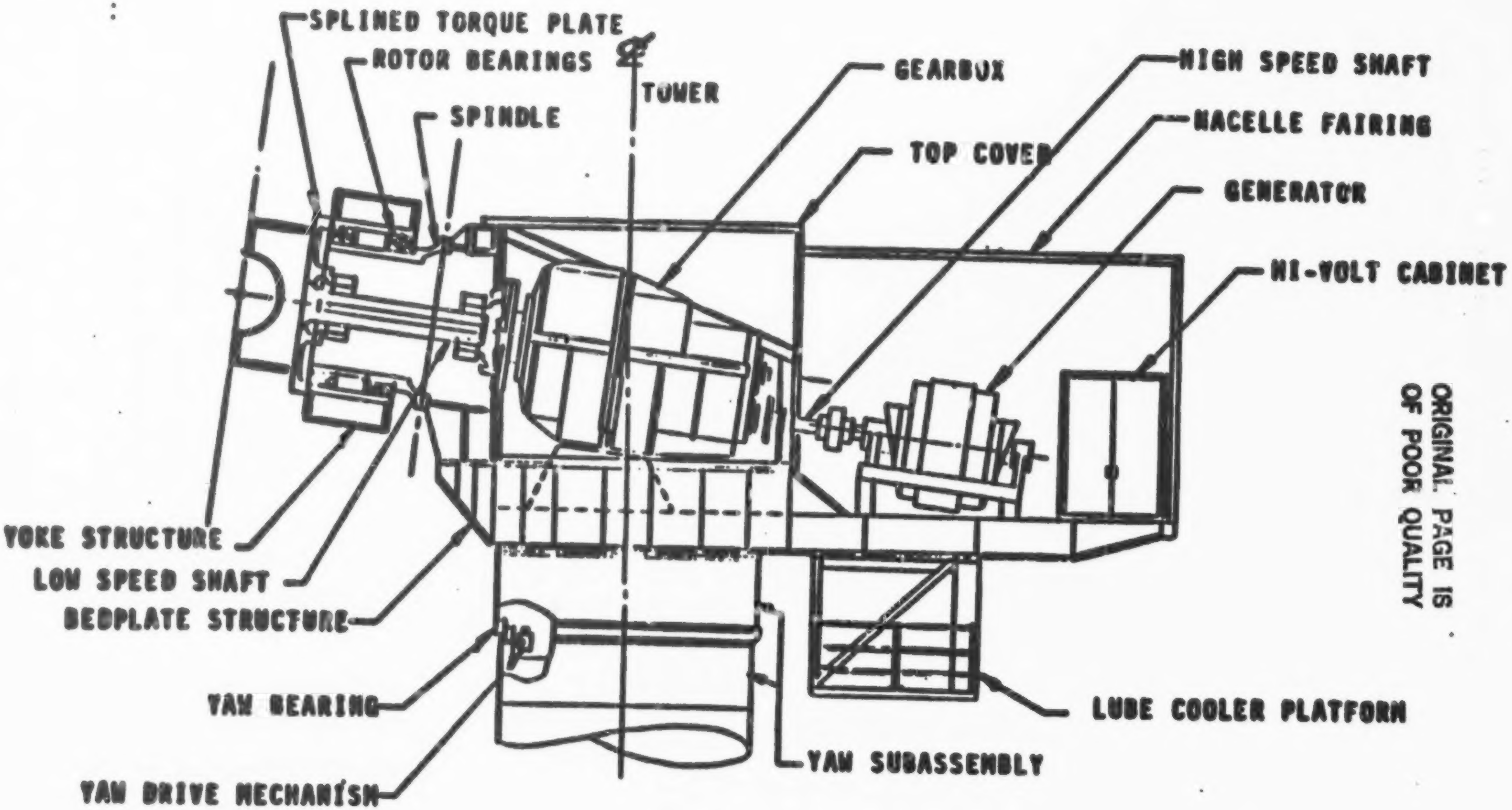
SPLINED TORQUE PLATE
ROTOR BEARINGS
SPINDLE
℄ TOWER
GEARBOX
TOP COVER
HIGH SPEED SHAFT
NACELLE FAIRING
GENERATOR
HI-VOLT CABINET
YOKE STRUCTURE
LOW SPEED SHAFT
BEDPLATE STRUCTURE
YAW BEARING
YAW DRIVE MECHANISM
YAW SUBASSEMBLY
LUBE COOLER PLATFORM

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Figure 10-29 Yoke and Gearbox Field Assembly

When the electrical components are installed and connected in the nacelle, the cycloconverter is installed in the electrical equipment building, shown in Figure 10-30. Then the isolation transformer, power factor capacitors, harmonic filters and switchgear line-up are installed. Next the station battery, the uninterruptible power supply for the control system, the 30 kVA transformer, electronics and interface cabinet are installed. The system display, operator terminal, control data system and ground multiplexer are also installed.

After the erectors mount the tower cable support brackets, the power control, and service and sensor cable assemblies are connected at the yaw sliprings, and run through the tower and foundation into the electrical equipment building.

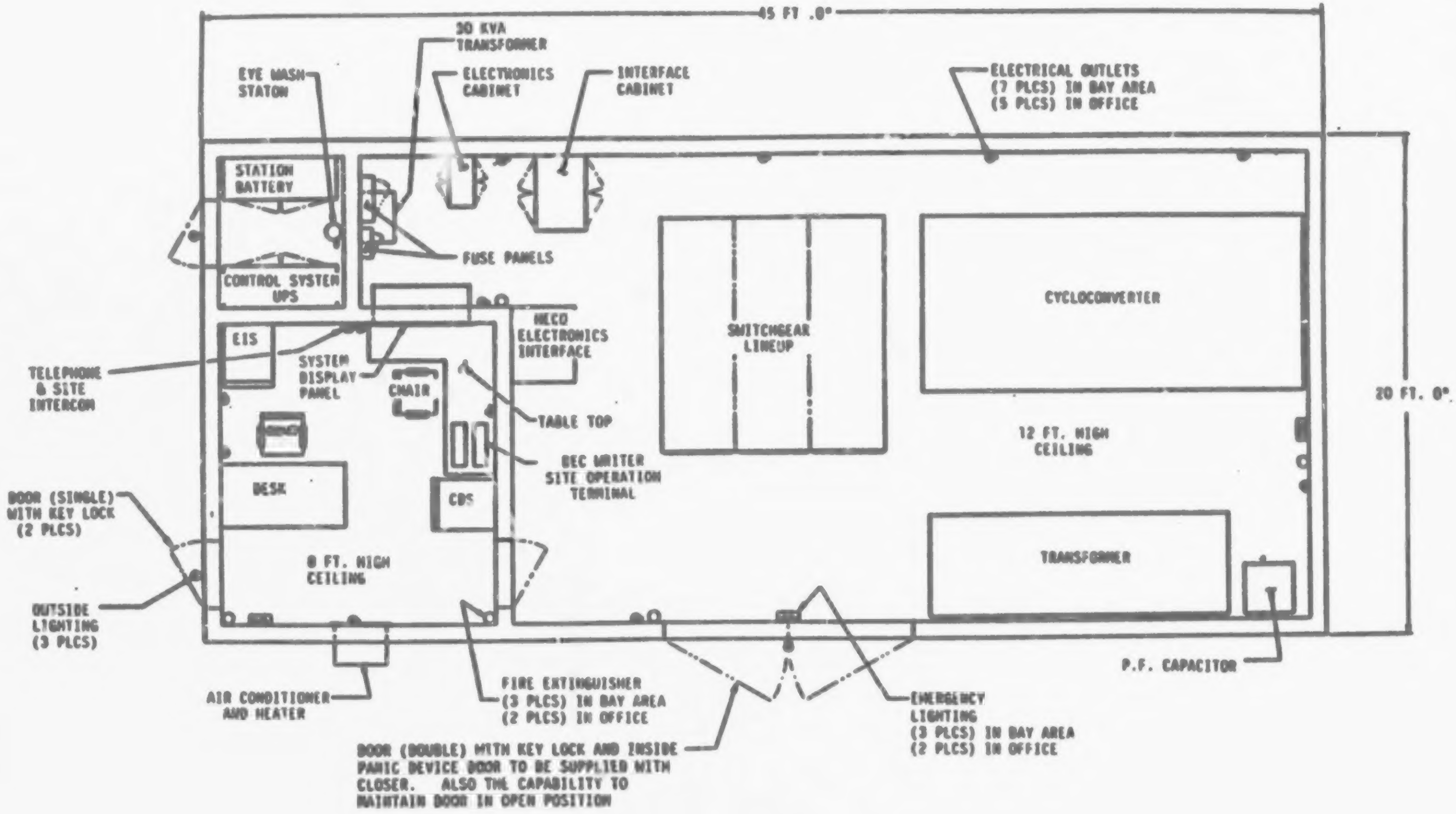

45 FT .0"
20 FT. 0"
30 KVA TRANSFORMER
EYE WASH STATON
ELECTRONICS CABINET
INTERFACE CABINET
ELECTRICAL OUTLETS (7 PLCS) IN BAY AREA (5 PLCS) IN OFFICE
STATION BATTERY
CONTROL SYSTEM UPS
FUSE PANELS
EIS
HECO ELECTRONICS INTERFACE
SWITCHGEAR LINEUP
CYCLOCONVERTER
TELEPHONE & SITE INTERCOM
SYSTEM DISPLAY PANEL
CHAIR
TABLE TOP
DEC WRITER SITE OPERATION TERMINAL
12 FT. HIGH CEILING
DESK
CDS
DOOR (SINGLE) WITH KEY LOCK (2 PLCS)
8 FT. HIGH CEILING
TRANSFORMER
OUTSIDE LIGHTING (3 PLCS)
P.F. CAPACITOR
AIR CONDITIONER AND HEATER
FIRE EXTINGUISHER (3 PLCS) IN BAY AREA (2 PLCS) IN OFFICE
EMERGENCY LIGHTING (3 PLCS) IN BAY AREA (2 PLCS) IN OFFICE
DOOR (DOUBLE) WITH KEY LOCK AND INSIDE PANIC DEVICE DOOR TO BE SUPPLIED WITH CLOSER. ALSO THE CAPABILITY TO MAINTAIN DOOR IN OPEN POSITION

Figure 10-30 Site Electrical Equipment Building

11.0 SITE AND ERECTION

11.0 SITE & ERECTION

11.1 GENERAL REQUIREMENTS

The site shall provide a level area for the construction and erection of the wind turbine generator. The terrain will be generally flat, with no significant obstructions to airflow in the upwind direction. Any obstructions or local increases in ground elevation within a radius of 4,000 ft. of the tower, shall be limited to 30 ft. above the ground elevation at the tower. Good drainage and nearly continuous access for operation and maintenance are required. The site shall be accessible to conventional rail or truck or both types of transportation and shall provide appropriate interfaces with the utility power grid and the utility power dispatch control.

11.1.1 AREA

The minimum area required for construction and erection of the wind turbine generator is 480 by 200 ft. An additional temporary area, 480 by 200 ft., is required for staging and tower fabrication. This temporary area may adjoin the site or be within one mile of it. Both areas shall be graded to a maximum slope of 1%. The use of land during operation may be limited to 100 by 300 ft. with limited air rights and access for maintenance equipment on adjacent land. A buffer zone, with a 5,000-ft. radius from the tower, with limited public access, is desirable for safety considerations.

11.1.2 ACCESS

An access road shall be provided from the nearest public road to the site. It must have the following characteristics:

a) The all-weather roadbed must be either 24 ft. wide or 18 ft. wide with turn-offs. The road must have a one-time maximum load capability of 300,000 lbs. gross weight, and a normal maximum load capability of 180,000 lbs. gross weight and 4,000 lb. per wheel.

b) Right-of-way around corners must accommodate a load that is 100 ft. long, with 70 ft. between axles, and 16 ft. wide.

c) The maximum grade is 11%, and maximum superelevation is 2%.

d) The minimum overhead clearance is 20 ft.

e) The minimum turn radius is 75 ft., measured to the inside of the roadbed.

If the temporary area for staging and tower fabrication does not adjoin the wind turbine generator site, a road with similar characteristics shall be provided between the temporary area and the site.

11.1.3 GEOTECHNICAL REQUIREMENTS

The geotechnical requirements for the wind turbine generator site design are:

a) Seismic conditions no worse than those specified in the Unified Building Code for Seismic Classification Zone 3.

b) Soil to a minimum depth of 15 ft. from the surface.

c) Split spoon penetrations of 20 to 60 blows per foot and increasing with depth.

d) Design bearing pressure of 4,000 lbs/sq. ft.

e) Homogeneous soil and rock conditions to a minimum depth of 150 ft. with no significant voids.

11.1.4 ENVIRONMENTAL CONDITIONS

The site environmental conditions shall be:

a) Maximum Wind Speed at the hub height — 58.8m/s (110 mph)

b) Temperature — -40°C to +52°C (-40°F to +125°F)

c) Precipitation and Humidity
   Rain --- 4 in./hour
   Hail --- 1 in. in diameter, 50 lb/cu ft., 66.6 ft/sec impact velocity on horizontal and vertical surfaces.
   Humidity --- Exposure equivalent to MIL Std 210B

11.1.5 ELECTRICAL UTILITY NETWORK INTERFACE

The wind turbine will feed its output of up to 7300 kW into a 60Hz, 3-phase utility network. The connection to the utility network is at the terminals of a fused disconnect switch at the high voltage side of the site step-up transformer. The utility line shall provide between 0.05 and 0.45 per unit impedance per phase to an infinite bus equivalent on a 4.16 kV, 7.5 MVA base. It shall operate at no less than 11 kV and no more than 80 kV line to line.

When the wind turbine is not operating, auxiliary power shall be supplied from the utility grid as follows:

a) 80 kVA, 0.8 power factor, 60 Hz ± 1% for continuous consumption while the wind turbine is not generating. This includes power for the mobile data acquisition system.

b) 1000 kVA, 0.9 power factor, 60 Hz ± 1% for periods of up to 5 minutes for start-up, auxiliaries, and unloaded generator motoring during low wind conditions.

11.1.6 COMMUNICATION AND CONTROL INTERFACE

A minimum of two dedicated, voice grade, unswitched telephone circuits shall be provided between the wind turbine generator site and the utility's remote operator or dispatcher location.

11.2 SITE ENGINEERING, OAHU, HAWAII

Site engineering includes the following tasks: determining the suitability of sites for the wind turbine generator, defining the site development requirements, subsurface investigations, soils reports, foundation design recommendations, obtaining permits and establishing the site plot plan.

A site near Kahuku Point, Oahu, Hawaii was identified for a MOD-5A wind turbine generator installation. The site engineering work that was completed and the work planned for this site are reported in this section.

11.2.1 SITE SURVEY

A site survey was conducted by the Hawaiian Electric Company (HECO) Civil Engineering Department. Contour maps of the site were prepared. Reference monuments that provide locations referring to the Hawaiian Plan Coordinate System Zone 3 were established . The results of this survey are documented on HECO drawings 27596 and 27597.

11.2.2 AREA MAP AND PLOT PLAN

A general site location plan and a preliminary plot plan were prepared for the Kahuku site. The plot plan provides an area, separated from the main tower and an erection area for the final assembly of the blade. This area permits assembly and erection to be carried out simultaneously. An access road, which has been routed for a minimum gradient between the Military Access Road "C" and the site, is also provided. A separate staging and tower fabrication area is located about .5 miles northeast of the wind turbine generator site. The plot plan can be finalized when an acceptable soils investigation and foundation design recommendations report are received.

11.2.3 SUBSURFACE INVESTIGATION

A subsurface investigation shall be conducted at the site to verify that subsurface conditions are compatible with the foundation stability requirements and to establish the design criteria for the foundations. It is estimated that three borings, 90 to 120 ft. deep, will be required to determine the subsurface conditions. The void ratio and dynamic shear modulus must be determined, using an acceptable seismic method. The seismic properties of the site, using the Uniform Building Code, must be established.

The key factors in the foundation design requirements are:

- Settlement -- Total 1.0 in.
  Differential Tilt 1:250
- Rocking Motion -- Zero to Peak Amplitude 10^{-4} radians for $4x10^8$ cycles of the mean average base ring moment
  (Rated value: see section 7.4.1)
- Seismic Classification UBC Zone 3

A model specification for Soils and Foundation Investigation, and a preliminary foundation design criteria report are provided in the appendix to this report.

11.3 SITE OPERATIONS PLAN

11.3.1 ORGANIZATION

A GE team will be established on the job site to direct the work and to ensure that the work complies with the technical specifications, the contract, and all applicable regulations.

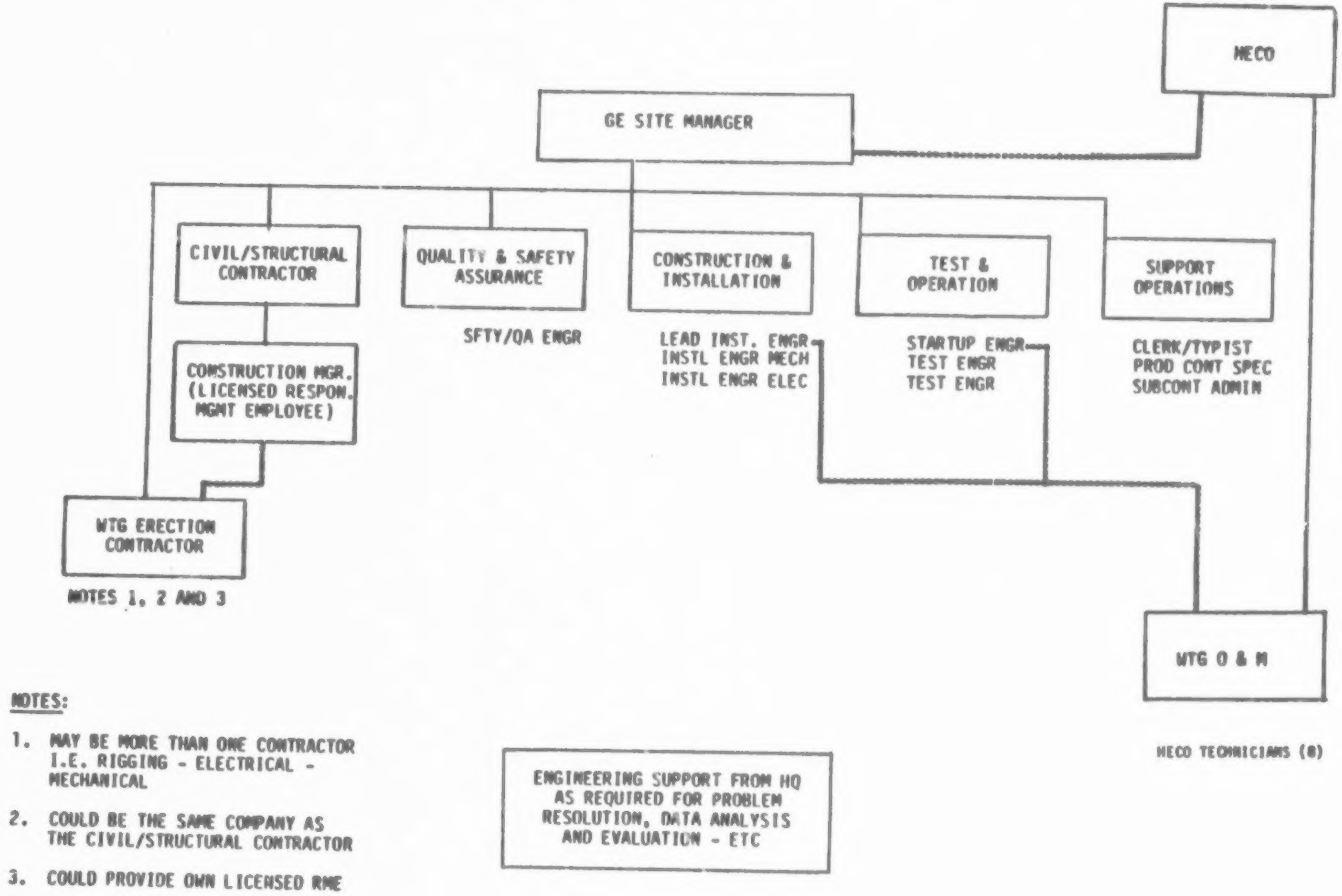
The GE team will also provide the primary working interface with the customer, provide hands-on training of customer personnel, perform checks and starting operations, and perform the preliminary operation of the MOD-5A wind turbine generator.

A preliminary organization chart for the Kahuku, Oahu, Hawaii installation is shown in Figure 11-1

11.3.2 WORK PLANNING, AUTHORIZATION AND CONTROL

The basic tool for work planning, authorization and control will be the task package. The elements of the task package are:

- A description of the work to be performed.
- A detailed schedule for the performance of the work.
- A list of the parts, components and other materials required to complete the work.
- Process plans and procedures containing detailed instructions for the performance of the work.
- A list of all tools, fixtures, special equipment and support required for the performance of the work.
- Personnel requirements.
- Inspection requirements, check lists and certificates of completion, which will contain sign-off boxes for Quality Assurance, Installation Engineering and Customer representatives. (This certificate can be the basis for releasing an element of the wind turbine generator, from the construction contractor to GE for testing. The form could also be the basis for an incremental payment schedule.)
- An engineering documentation package that defines the parts, components or material to be installed. The package includes a list of the applicable codes and standards.


HECO
GE SITE MANAGER
CIVIL/STRUCTURAL CONTRACTOR
QUALITY & SAFETY ASSURANCE
CONSTRUCTION & INSTALLATION
TEST & OPERATION
SUPPORT OPERATIONS
SFTY/QA ENGR
LEAD INST. ENGR
INSTL ENGR MECH
INSTL ENGR ELEC
STARTUP ENGR
TEST ENGR
TEST ENGR
CLERK/TYPIST
PROD CONT SPEC
SUBCONT ADMIN
CONSTRUCTION MGR. (LICENSED RESPON. MGMT EMPLOYEE)
WTG ERECTION CONTRACTOR
NOTES 1, 2 AND 3
WTG O & M
HECO TECHNICIANS (8)
ENGINEERING SUPPORT FROM HQ AS REQUIRED FOR PROBLEM RESOLUTION, DATA ANALYSIS AND EVALUATION - ETC

NOTES:

1. MAY BE MORE THAN ONE CONTRACTOR I.E. RIGGING - ELECTRICAL - MECHANICAL
2. COULD BE THE SAME COMPANY AS THE CIVIL/STRUCTURAL CONTRACTOR
3. COULD PROVIDE OWN LICENSED RME

Figure 11-1. Preliminary Organization Chart for the Installation in Kahuhu, Oahu

11.3.2.1 Preparation

Each task package will be prepared by the responsible installation engineer with assistance from design engineering, quality engineering, manufacturing engineering and the construction and installation contractor, as appropriate. Each task package will be reviewed and approved by Quality Assurance and Safety, the Installation and Test Operations Manager, and Engineering.

11.3.2.2 Readiness Review

Before authorization is granted to proceed with the work defined in the task package, a readiness review shall be conducted by the Installation and Test Operations Manager or a designated representative. Attendees of the readiness reviews shall include:

- Responsible Installation Engineer
- Quality/Safety Engineer
- Installation and Test Operations Manager
- Construction/Installation Contractor Representative
- Customer Representative

The readiness review will verify that all planning is complete, that all material, equipment and other supporting requirements are available, and that adequate preparation, including safety checks, personnel briefing, a dry-run of the procedure, etc., have been performed.

11.3.2.3 Task Package Breakdown

The task packages for the wind turbine generator installation are listed below:

1. Foundation
2. Electrical Equipment Building
3. Tower and Elevator
4. Ground Equipment Installation
5. Yaw Assembly
6. Nacelle Assembly
7. Blade Assembly
8. Rotor Assembly
9. Interconnecting Cables

11.3.3 LIFTING EQUIPMENT

The definition of the components to be handled during site assembly and erection operations is contained in the Statement of Work for Erection of the MOD-5A Wind Turbine Generator document number SOW-MOD-5A-WTG-33. This document is included in the appendix to this report. The heaviest load to be lifted is the rotor assembly, which weighs 300,000 pounds. Allowing 50,000 pounds for fixtures, slings, and a spreader bar, the maximum hook load is 350,000 pounds.

The lifting equipment considered for the erection include:

- #4600 Ringer Crane
- High Lift Configuration Mobile Crane (American Super Skyhorse or DeMag)
- Tower Mounted Twin Booms

Availability and cost were the major considerations in selecting the lifting equipment. The availability of the equipment on a short lead time for the erection, maintenance and repair operations is a key factor. Cost estimates for the equipment are given in Table 11-1. Note that shipping, set-up and dismantling are the major cost elements.

In view of the high cost and limited availability of imported lifting equipment, the erection plan for Hawaii was based on the use of locally available equipment and the twin booms. There are two 200-ton class mobile cranes available on Oahu, HA, each with a boom length of up to 270 ft. One of these cranes is required on the site for the duration of the tower erection, assembly and installation operations. The other crane is required during the set-up and removal of the twin booms, which requires two cranes. The twin boom and associated winches, sheaves and blocks are contained in the inventory of the tower fabricator. These items are available on short notice and are easily shipped.

Since the twin boom lifting configuration limits the load hook position relative to the tower centerline, the use of counterweighted fixtures will be necessary for the installation of certain components. Also, to accommodate the twin booms, modifications are required on the tower to provide the structural interfaces. These items will incur additional costs, estimated at $100,000.

Table 11-1 Lifting Equipment Cost Estimates

$K X 1000 (1983)	
#4600 Ringer	
Shipping, set-up and dismantling	750
Rental for 16 weeks (inc. operator and oiler)	240
Total	990
Super Skyhorse	
Shipping, set-up and dismantling	500
Rental for 16 weeks (inc. operator and oiler)	240
Total	740
Twin Booms	
Link Belt TC258	
Set-up and dismantle	25
Rental for 16 weeks (inc. operator and oiler)	160
Crane #2	
Set-up and dismantle (x2)	30
Rental for 6 days	10
Twin Booms	
Shipping, set-up and dismantle	125
Rental for 8 weeks	24
Total	374

Note: These estimates include tower erection and the assembly and installation of the wind turbine generator.

11.3.4 OUTLINE ASSEMBLY AND ERECTION PROCEDURES

This section outlines the operations that must be performed on the site to erect the wind turbine generator. Each operation requires a detailed definition, as part of the task package preparation discussed in section 11.3.2.

The extent of the site assembly work depends on the final shipping plan, which has not been prepared. The shipping plan determines how the subsystems are disassembled after they are assembled and checked in the factory.

Sketches illustrate the concepts developed for the erection of the wind turbine generator. These sketches may be revised during the detailed definition of the erection procedures.

The prerequisites for the start of yaw and nacelle assembly and erection are:

- Completed tower erection.
- Completed elevator installation; elevator in service, using temporary power hook-up.
- Work platforms at the top of tower in place.
- Twin booms and hoisting equipment installed, proof loaded and ready for operation.
- Auxiliary hoist equipment (deadman, blocks, tuggers, tag lines, etc.) installed and ready for operation.
- Final assembly and erection procedures reviewed and approved.
- Check lists of all tools, fixtures and assembly and erection aids completed.
- Link belt TC 258 (or equivalent) crane with 50 ft. boom available to support assembly and erection. (The crane's capacity at a 20-ft. radius should be 250K lbs. over rear - 220K lbs. over side.)
- 10-ton mobile crane and fork lift truck available to support assembly and erection.

11.3.4.1 Yaw Assembly

- Lift the assembly from the transporter and boom into position at the base of the tower.
- Attach the counterweighted lifting fixture.
- Prepare the twin booms and hoisting equipment for the yaw lift.
- Complete the readiness review.
- Lift the yaw assembly into final position and align it with the tower.
- Girth weld the yaw to the tower.
- Change the hook position on the counterweighted lifting fixture, and release the fixture from the yaw assembly. Lower it to the ground.
- Clear the ground area for the next operation.

This sequence is illustrated in Figures 11-2 through 11-6.

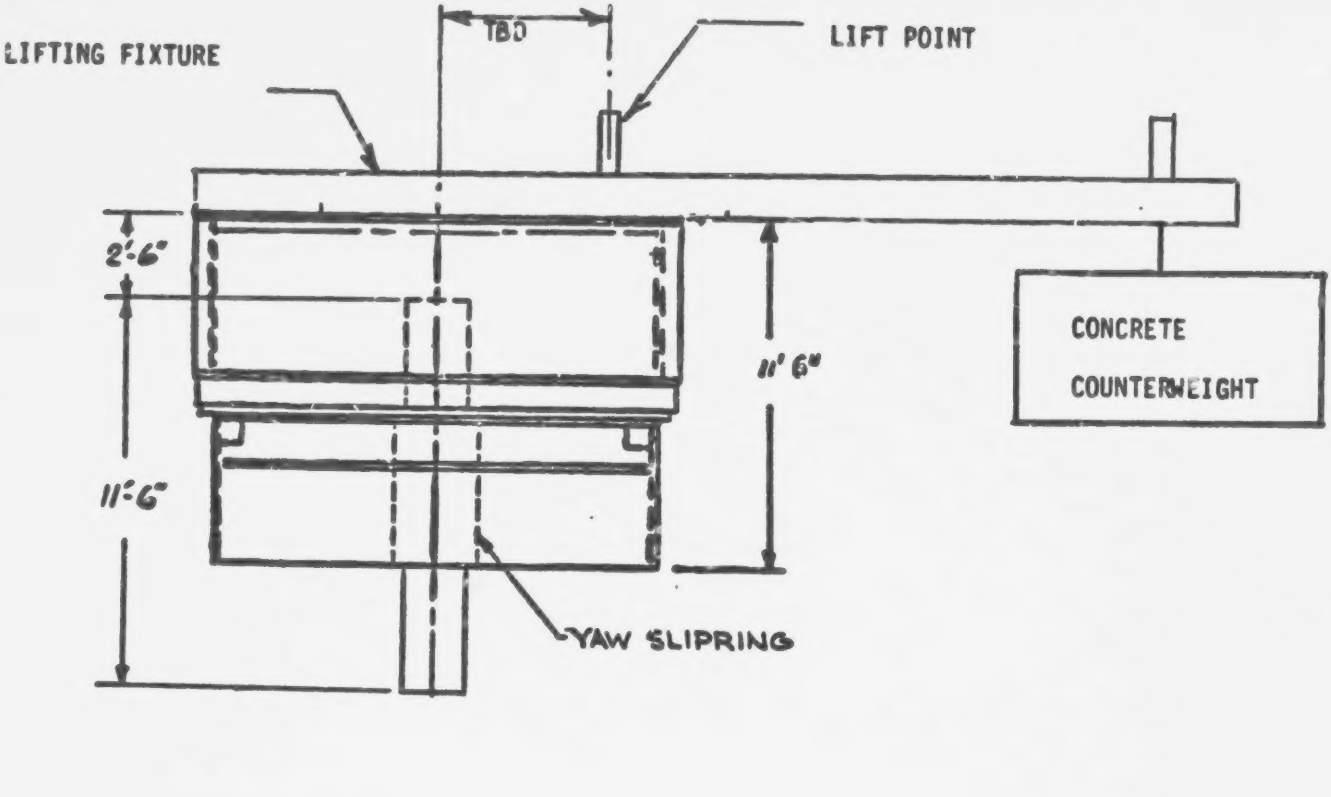

LIFTING FIXTURE
TBD
LIFT POINT
2'-6"
11'-6"
11'-6"
CONCRETE COUNTERWEIGHT
YAW SLIPRING

Figure 11-2. Yaw Erection
Module Weight with Lifting Fixture = 75,000 Lbs.

C-4

YAW ERECTION

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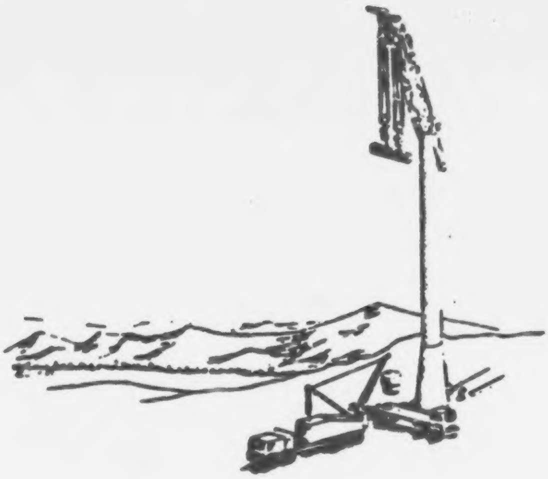

Figure 11-3. Unload

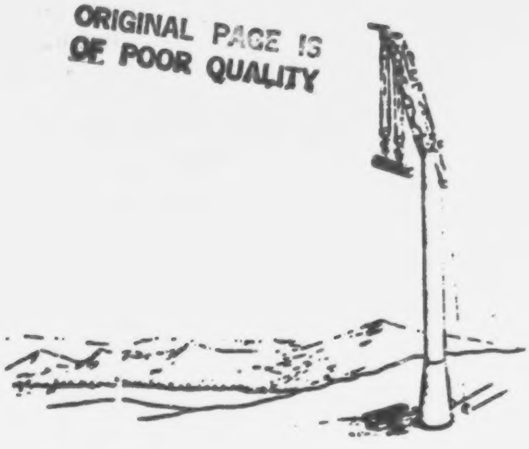

Figure 11-4. Assembly

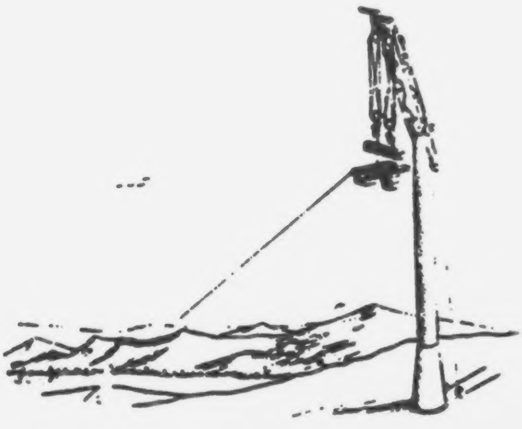

Figure 11-5. Lifting

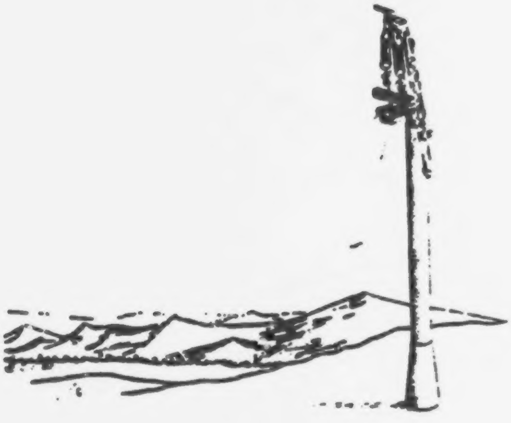

Figure 11-6. Landing on Tower

11.3.4.2 Bedplate Assembly

- Unload the bedplate from the transporter and boom into position at the base of the tower.
  Note: The crane capacity may be marginal for this booming . It may be necessary to skid from the maximum crane radius (30 ft.) to the base of tower. The weight of the bedplate, spreader bar and slings is 160,000 lbs.
- Unload the rotor adaptor, boom into position on the bedplate (70,000 lbs. with spreader bar and slings.)
- Assemble the rotor support structure and other platforms and walkways.
- Unload and install the lubrication platform and cooler.
- Unload the generator, boom into position on bedplate (60,000 lbs. with spreader bar and slings.)
- Install the generator and auxiliaries.
- Prepare the twin booms and hoisting equipment. Rig for the bedplate lift and install counterweight.
- Complete the readiness review.
- Lift the bedplate assembly to the final position on yaw.
- Assemble the bedplate to the yaw, and hook up all wiring and tubing to the bedplate and yaw.
- Remove the counterweight.
- Install temporary power and controls to yaw drive subsystem and check the yaw drive.
- Install temporary skid, come-alongs and other auxiliary devices in preparation for the gearbox installation.
- Clear the ground area for the next operation.

This sequence is illustrated in Figures 11-7 through 11-11.

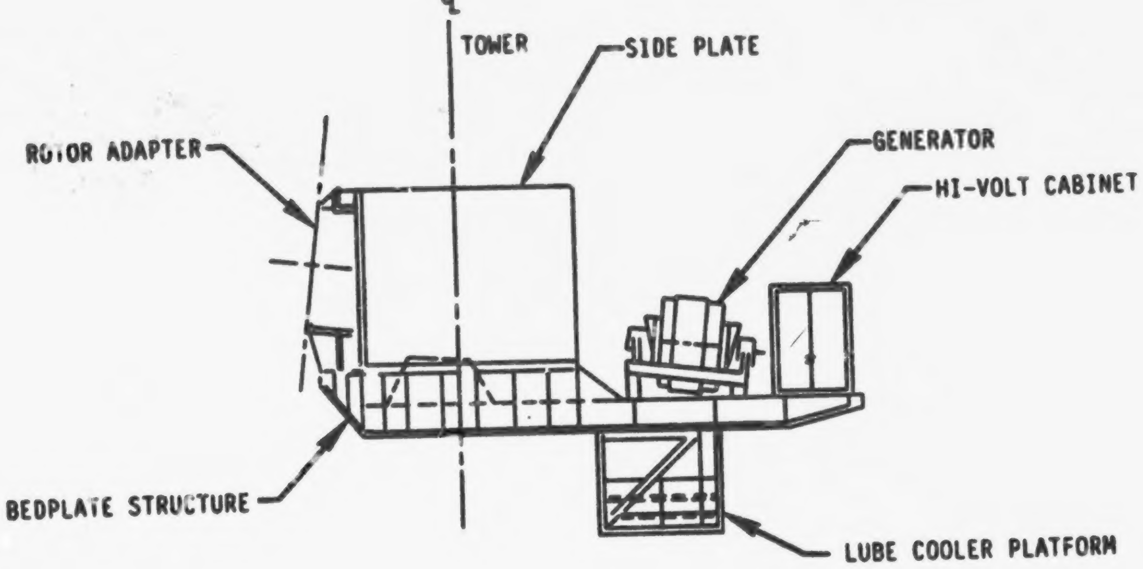
℄ TOWER
SIDE PLATE
ROTOR ADAPTER
GENERATOR
HI-VOLT CABINET
BEDPLATE STRUCTURE
LUBE COOLER PLATFORM

Figure 11-7 Bedplate Erection Module
Weight with Spreader Bar, Slings and Counterweight = 300,000 lbs.

BEDPLATE ERECTION

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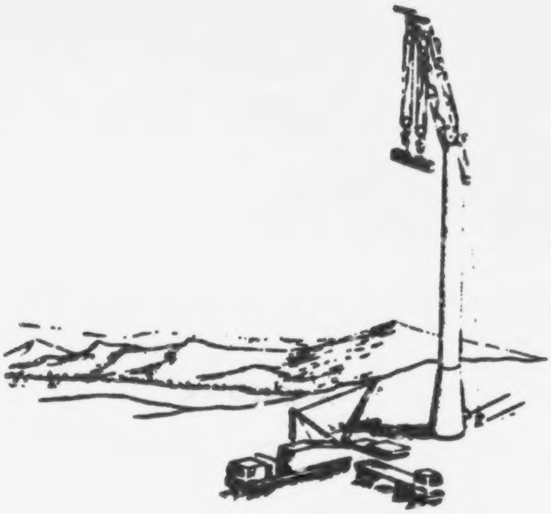

Figure 11-8. Unload

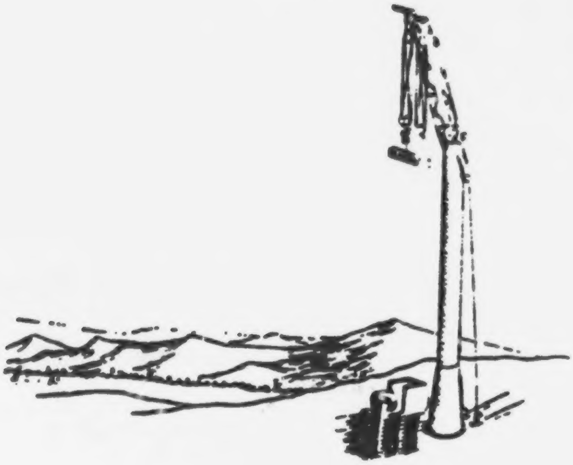

Figure 11-9. Assembly

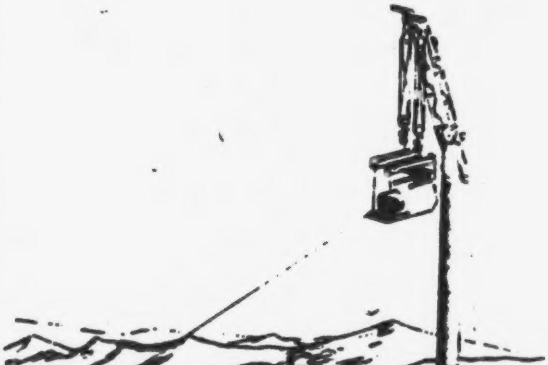

Figure 11-10. Lifting

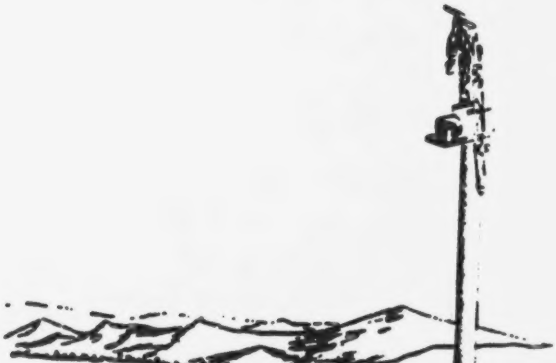

Figure 11-11. Landing on Yaw Assembly

11.3.4.3 Gearbox

- Unload the gearbox and boom into position at the base of the tower (160,000 lbs. with spreader bar and slings).
- Prepare the twin booms and hoisting equipment, rig for gearbox lift.
- Complete the readiness review.
- Lift the gearbox into the interim position (swing in over generator and land on temporary skid).
- Lower the twin booms to a horizontal position.
- Using the yaw drive and temporary electrical hookup, yaw through 180°. (Generator is now located on the same side of tower as the twin boom seats and the bedplate is ready to receive the yoke).
- Clear the ground area for the next operation.

The gearbox is shown in Figure 11-12.

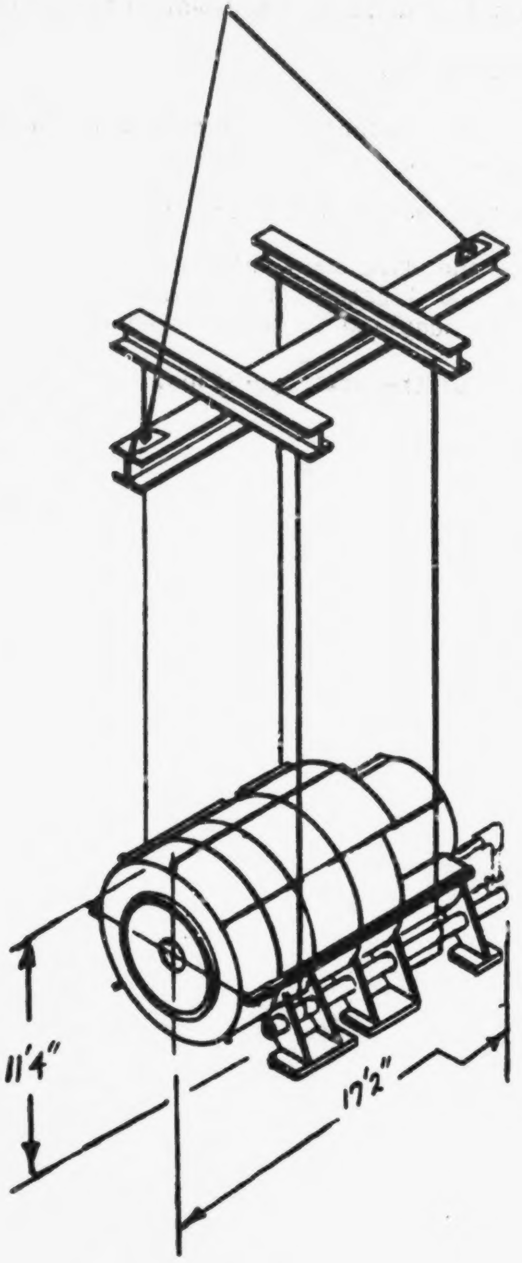

Figure 11-12. Gearbox Erection Module 160,000 lbs. with Spreader Bar and Slings

11.3.4.4 Yoke Assembly

- Unload the yoke assembly and place at the base of the tower (230,000 lbs. with spreader bar and slings) with the teeter caps off and ears pointing down with torque plate assembled to yoke.
- Unload the low speed shaft. Lower the shaft into the yoke and engage the spline.
- Assemble the torque plate flanges, coupling seals and low speed shaft positioning fixture.
- Prepare the twin booms, hoisting equipment and positurns. Rig for yoke erection.
- Install temporary work platforms in the rotor support area. Install temporary power and control hook-up for turning gear motor.
- Complete the readiness review.
- Using the twin boom with spreader bar and positurns and the crane, lift and rotate yoke assembly to get the low speed shaft 7° down from horizontal. Attach stabilizing sling.
- Lift the yoke assembly and land end of low speed shaft on the support fixture inside rotor adaptor.
- Remove the stabilizing sling on the low speed shaft.
- Maneuver the yoke into the final position on the rotor adaptor.
- With the low speed shaft supported by a support or jacking fixture in the rotor adaptor, remove the low speed shaft positioning fixture from the spindle.
- Assemble the spindle to the rotor adaptor.
- Remove the positurn slings.
- Skid the gearbox into its final location, using the support or jacking fixture and turning the gear to align the splines on the coupling.
- Assemble the gearbox to the bedplate, install wiring in the yoke.
- Remove temporary supports from the low speed shaft, skids, etc.
- Clear the ground area for the next operation.

The lifting part of this sequence is shown in Figures 11-13 through 11-18.

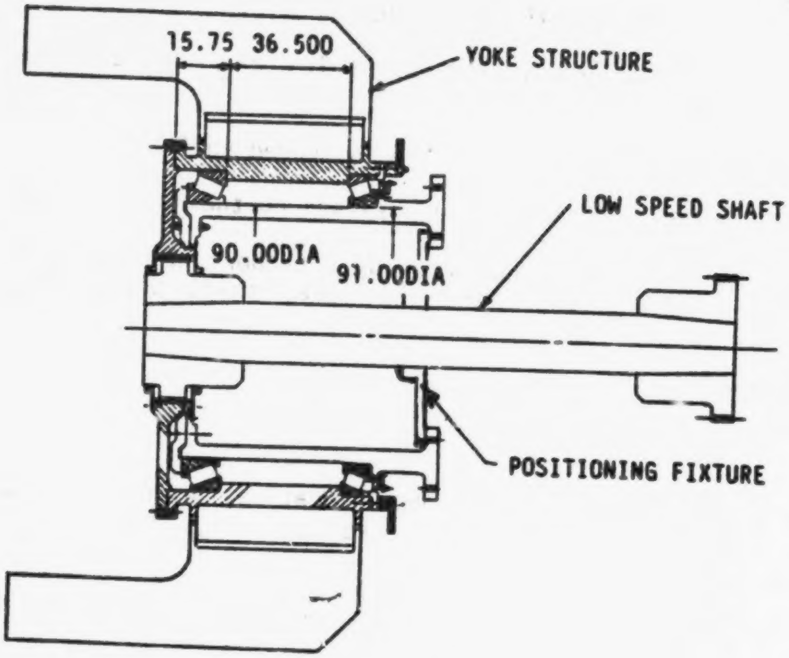
15.75
36.500
YOKE STRUCTURE
LOW SPEED SHAFT
90.00DIA
91.00DIA
POSITIONING FIXTURE

Figure 11-13 Yoke Erection Module
320,000 lbs. with Spreader Bar, Slings and Posíturns

YOKE ERECTION

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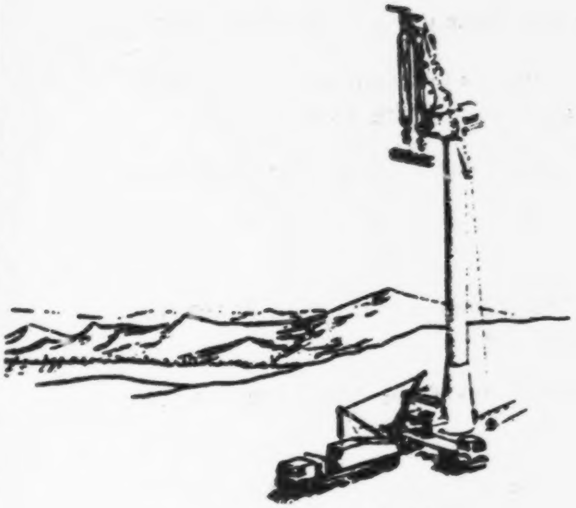


Figure 11-14. Unload

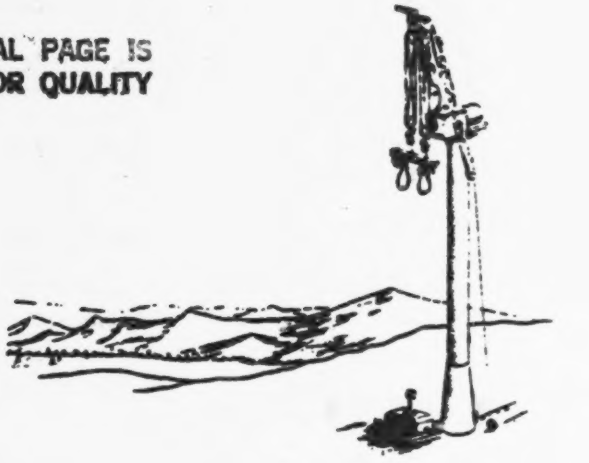


Figure 11-15. Assembly

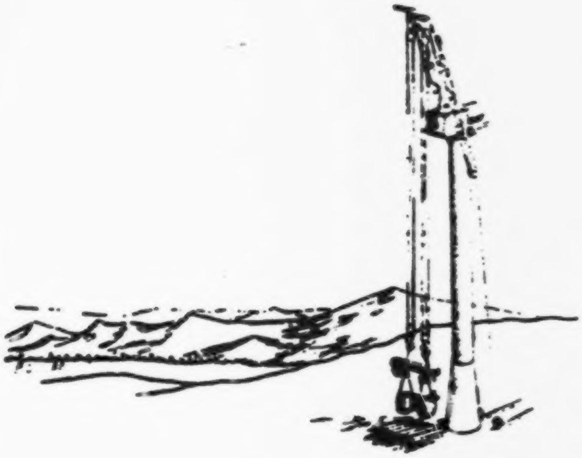
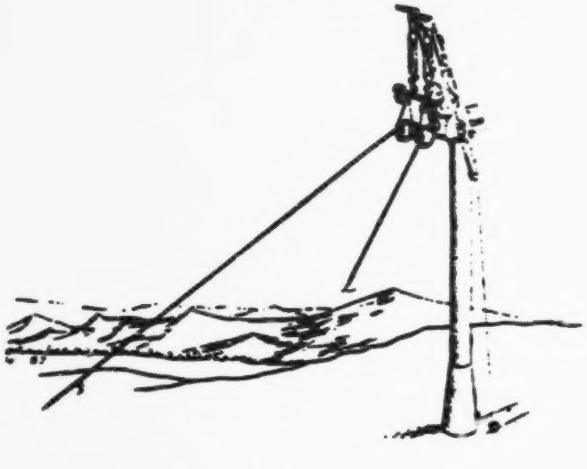


Figure 11-16. Rotate and Lift



Land End of Low Speed Shaft on Positioning Fixture
and Remove Stabilizing Sling

Figure 11-17.

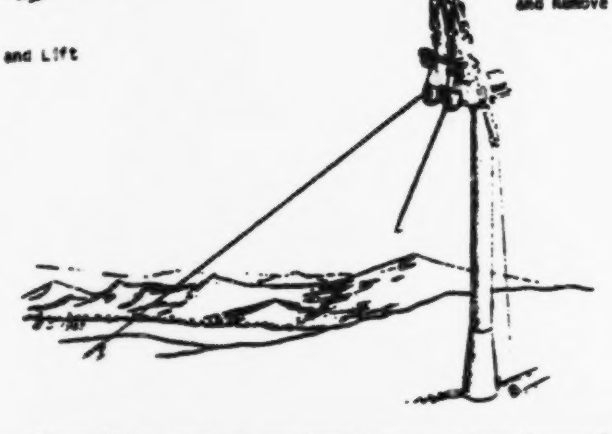


Figure 11-18. Maneuver into Final Location on Rotor Support Structure

11.3.4.5 Nacelle Assembly

- Lower the twin boom to a horizontal position
- Using the yaw drive and temporary electrical hookup, yaw through 180°.
- Unload the high speed shaft assembly, rotor slipring assembly, and fairing assembly, and position them at the base of the tower.
- Prepare the twin booms and hoisting equipment. Rig for nacelle assembly.
- Complete the readiness review.
- Lift the high speed shaft assembly to its final position. Assemble the shaft assembly to the gearbox and generator.
- Lift the rotor slipring to final position. Assemble the slipring to the gearbox.
- Lift the fairing to final position. Assembly the fairing to the bedplate.
- Unload the top plate and position it at the base of the tower.
- Lift the top plate to its final position. Assemble the top plate to the side plates.
- Hook up all nacelle wiring and plumbing.

11.3.4.6 Rotor

- Assemble the rotor at the site assembly area and perform ground level inspections and checks in accordance with a detailed procedure (later).
- Prepare skids, tugger and towing cables. Rig in preparation to move rotor.
- Skid the rotor assembly into position at the base of the tower.
- Prepare twin booms, hoisting equipment and positurns. Rig for rotor erection.
- Complete the readiness review.
- Lift the rotor from the bunks. Using the positurns, rotate the rotor and position it with the teeter shaft 7° from vertical.
- Raise the rotor and maneuver the teeter shaft into the yoke. Attach the teeter bearing caps.
- Remove the positurn slings from rotor.
- Install the rest of the hydraulic plumbing and wiring.
- Remove the rest of the lifting fixtures and rigging.
- Clear the ground area for the next operation.
- Rotate rotor into vertical position using turning gear motor.
- Complete teeter bearing preloading

This procedure is illustrated in Figures 11-19 through 11-22.

11.3.5 SCHEDULES

Schedules for the preparation of the site, the construction and erection of the wind turbine and the post-installation testing are shown in Figures 11-23 through 11-25. These plans schedule work to be performed by GE, NASA, and the Utility (HECO in this case).

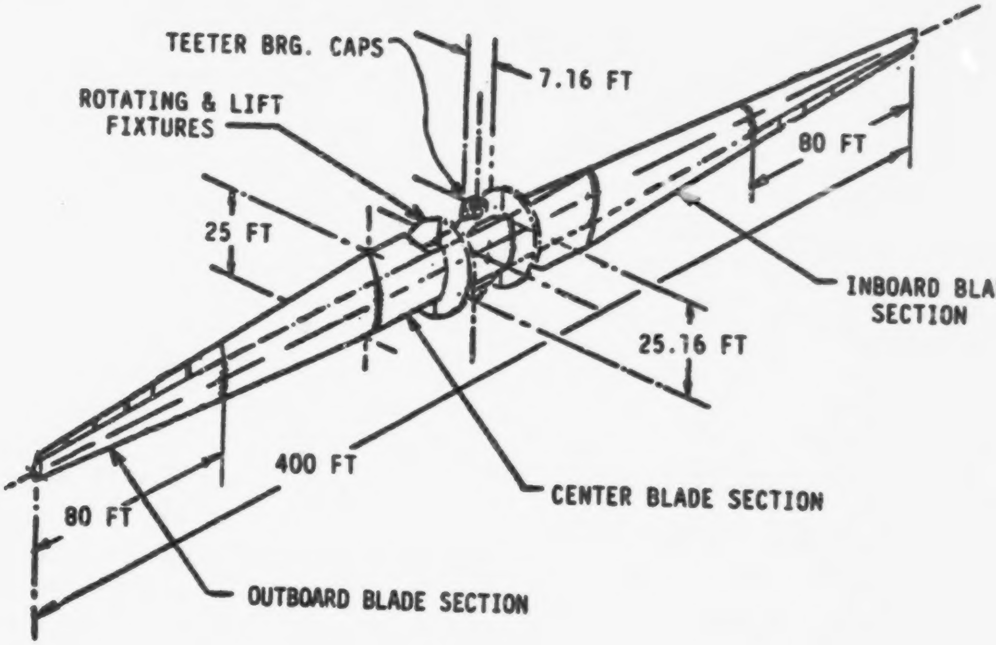

TEETER BRG. CAPS
7.16 FT
ROTATING & LIFT FIXTURES
80 FT
25 FT
INBOARD BLADE SECTION
25.16 FT
400 FT
CENTER BLADE SECTION
80 FT
OUTBOARD BLADE SECTION

Figure 11-19 Rotor Erection Module
Weight with Lifting Fixtures: 530,000 lbs.

ROTOR ERECTION

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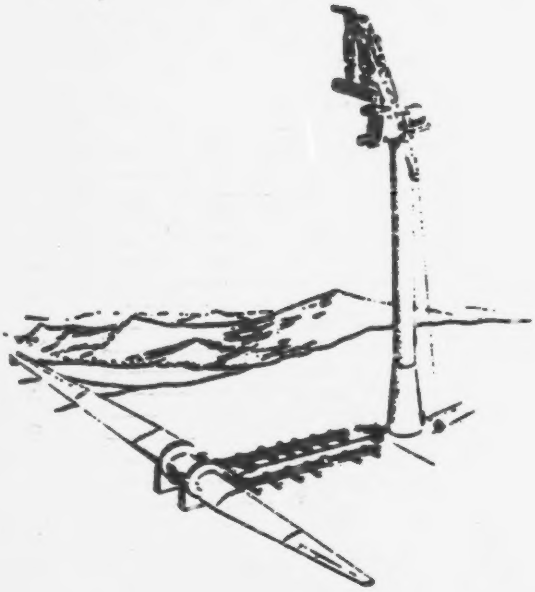

Figure 11-20. Skid Rotor from Assembly Area to Base of Tower

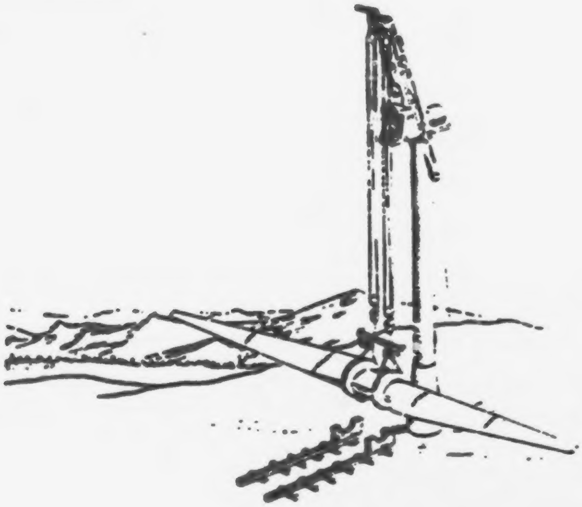

Figure 11-21. Attach Lift Slings and Positurn Lifting Fixture

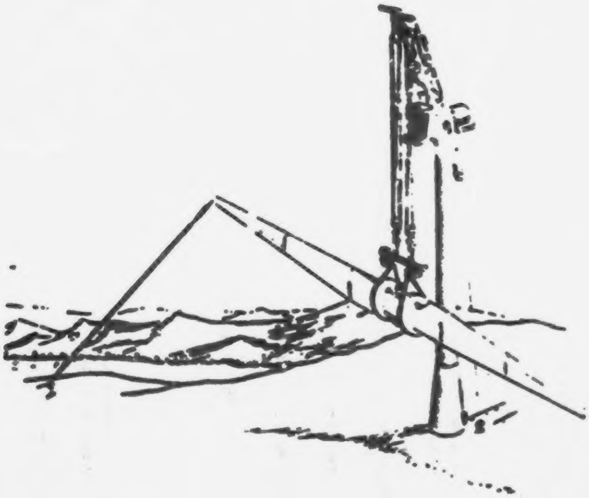

Figure 11-22 Rotate and Lift Rotor

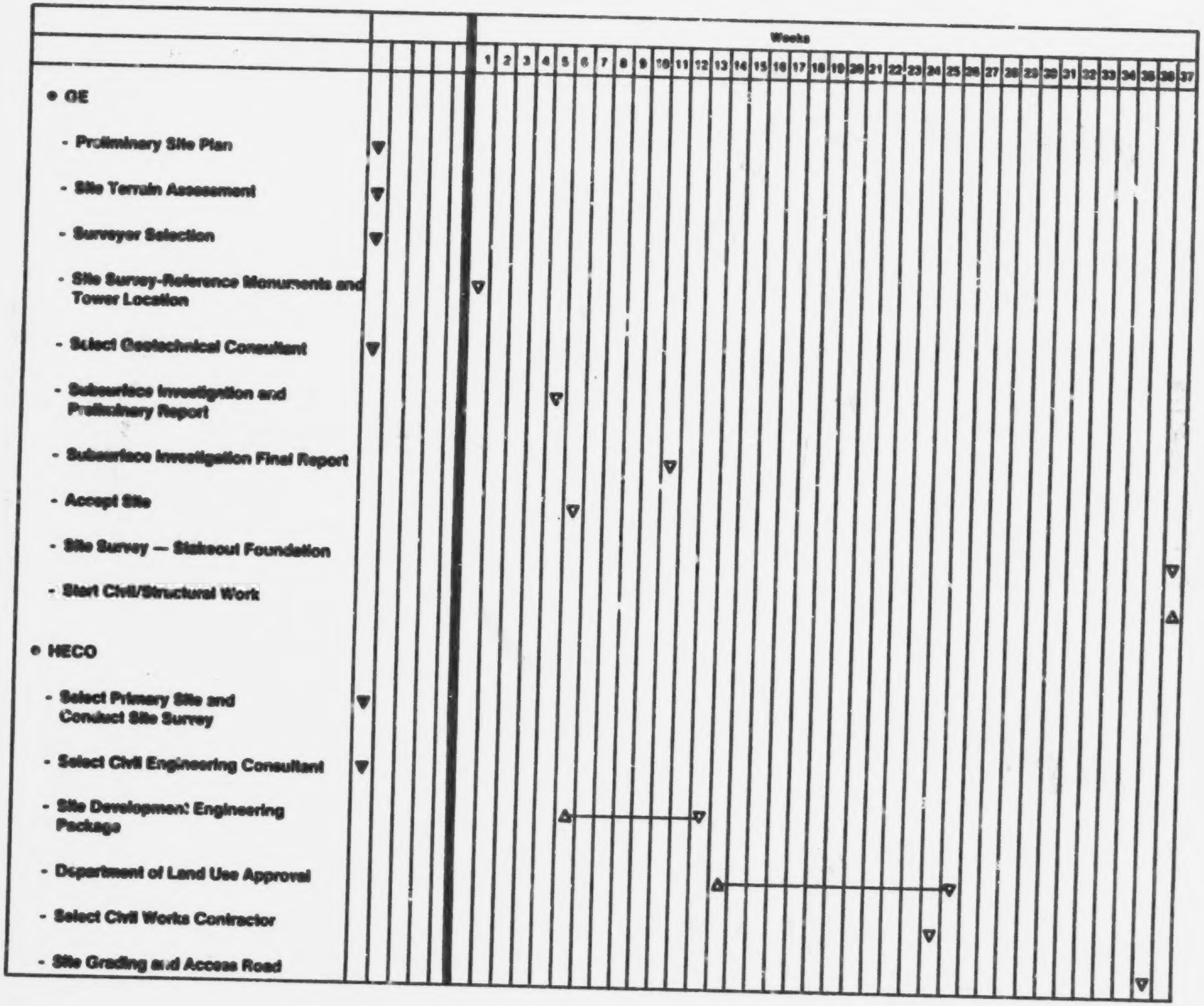

Figure 11-23 Schedule for Site Selection and Activation

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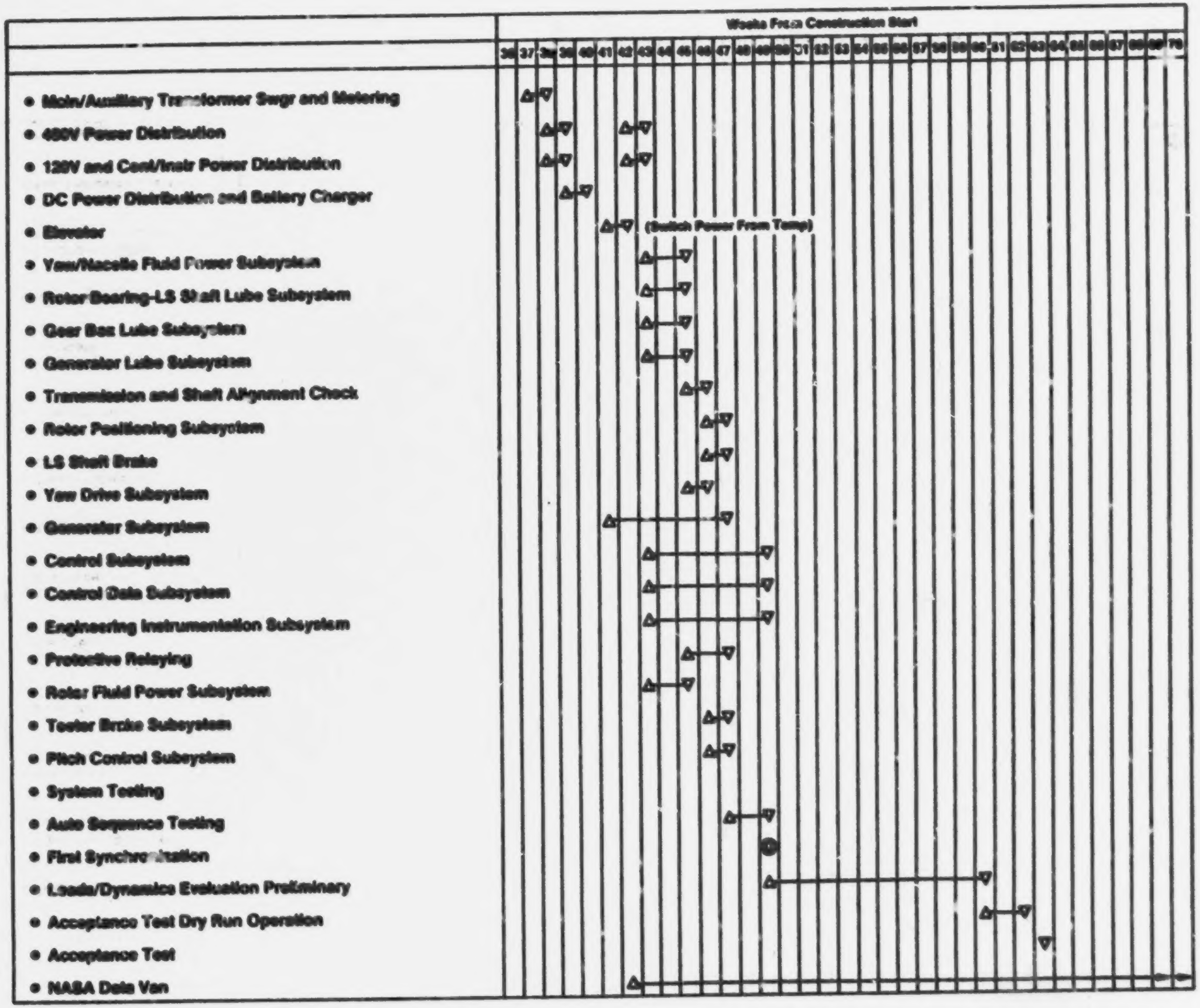

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Figure 11-24 Schedule for Construction and Erection

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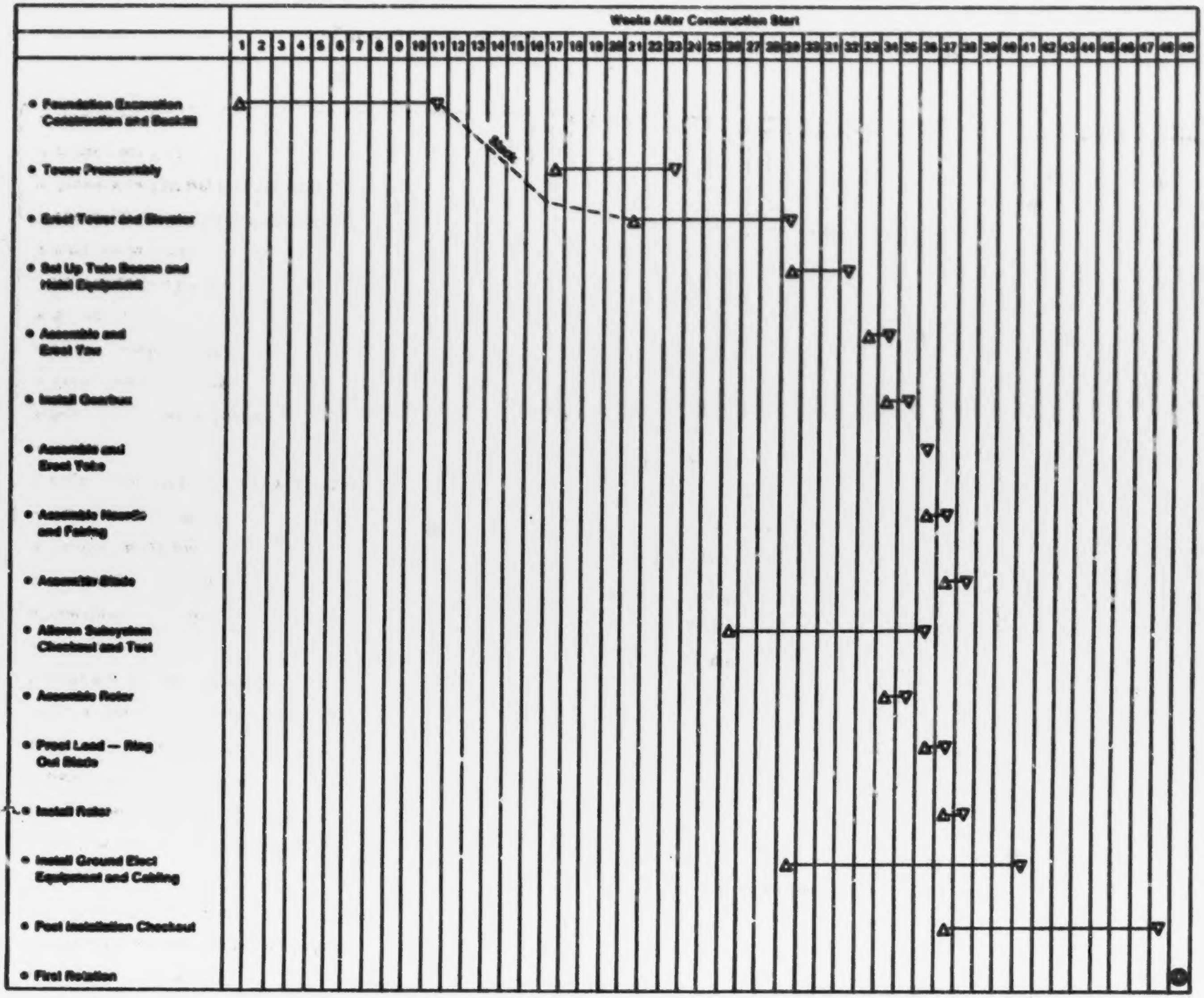

Figure 11-25 Schedule for Post-Installation Checks and Tests

Volume III
Book 2

12.0 QUALITY ASSURANCE

12.0 QUALITY ASSURANCE AND SAFETY

12.1 INTRODUCTION

This section defines Quality Assurance and Safety plans and provisions for use during the fabrication and erection of the MOD-5A wind turbine generator. A section is also provided to identify design margins as a result of stress analysis.

12.2 GENERAL

12.2.1 QUALITY ASSURANCE PLAN

The final version of the MOD-5A Product Assurance Program Plan is GE document 47A380018, Rev. D. The document was reviewed and approved by NASA. This document is included in the appendix of this volume.

12.2.2 SAFETY PLAN

The final version of the MOD-5A System Safety Plan is GE document 47A380019, Rev. B. The document was reviewed and approved by NASA. This document is included in the appendix to this volume.

12.2.3 CONFIGURATION CONTROL PLAN

The configuration control plan is included in the Appendix to this volume.

12.2.4 TEST HARDWARE INSPECTION REPORTS

Inspection reports document the discrepancies between specifications and the development test hardware that was delivered for development tests. The reports also document how the discrepant hardware was dispositioned. In all cases except one, the discrepancies were minor and the hardware was used in tests. In one case, however, the discrepancies on the threaded studs would have biased fatigue test results. For this reason the studs were not accepted for fatigue tests. Eighteen units were used for static tests, the others were replaced. The supplier replaced the units with parts that satisfied drawing's requirements. In a few of the discrepancies, because of the size and cost of the items, there was no alternative but to accept the material and take the discrepancies into consideration when the test results were evaluated. Note, that all hardware described in these defect reports is development test hardware; none of the items were planned for application on the operating wind turbine. Copies of these defect reports are included in the Appendix to this volume.

12.2.5 FACTORY INSPECTION AND TEST EQUIPMENT

This list is an estimate of the test equipment required for inspections and tests in the factory. The quantities and the cost, as of the fourth quarter of 1983, of each item are listed. In most cases these are catalog costs or verbal quotations. In a few cases the costs are estimated.

ITEM AND QUANTITY	INVESTMENT	EXPENSE	TOTAL COST
1. Oscilloscope System Tektronix Mod. 7854 1 at $19,530	19,530	-	19,530
2. Digital Multimeter Fluke 8600 A-01 4 at $1,120	4,480	-	4,480
3. Universal Counter/Timer Fluke 7261A 1 at $1,455	1,455	-	1,455
4. Function Generator Hp MOD 3312A 1 at $1125	1,125	-	1,125
5. Insulation Resistance Tester (0-2.5kVdc) Hipotronics HV-2.5 1 at $1,320	1,320	-	1,320
6. Dielectric Strength Tester (0-20kVdc) Hipotronics MOD 720-5 1 at $1,430	1,430	-	1,430
7. Phasemeter 1 at $200 (estimated)	200	-	200
8. Relay Test Set Multi-Amp SR-76A 1 at $7,945	7,945	-	7,945
9. Digital T/C Readout Omega 2168A-03 2 at $1,005	2,010	-	2,010

ITEM AND QUANTITY	INVESTMENT	EXPENSE	TOTAL COST
10. Digital T/C Readout Omega 2166A-03 2 at $875	1,750	-	1,750
11. Multipoint T/C Recorder Omega OM-271 2 at $4,100	8,200	-	8,200
12. Multipoint MV Recorder L&N Speedomax 250 2 at $3,564	7,128	-	7,128
13. Strain Gage Readout Meas. Group-Inc. P-3500 2 at $985	1,970	-	1,970
14. Strain Gage Sel. Sw (10 pos) Meas. Group Inc. SB-1K 2 at $875	1,750	-	1,750
15. Power Supplies Lambda LA-300 4 at $300	1,200	-	1,200
Lambda LA-350 4 at $300	1,200	-	1,200
16. Portable VOM Fluke 8020B 2 at $194	388	-	388
17. Ammeter, Clamp-on Weston MOD 633-Type VA-1 1 at $446	446	-	446
18. Realtime Theodolite System K&E - AIMS Includes: 2 - DT-1 Digital Theodolites 2 - RS232 Interfaces 1 - Multi. Unit 1 - 802 Controller 1 - Printer	$59,400	-	$59,400
19. Instrument Stands-Heavy Duty K&E 71-5025 2 at $1520	3,040	-	3,040
20. Laser Target System K&E - AIMS	10,000	0	10,000
21. Control Data System o Processor	50,000	-	50,000

ITEM & QUANTITY	INVESTMENT	EXPENSE	TOTAL COST
o CR Terminal o Printer o MAG Recorder o Strip Chart Recorder (Engineering to specify and select system components)	Note:	This estimate assumes availability of NASA-PIV VAN for data reduction	
22. Miscellaneous Tools o Torque Wrenches o Electrical Tool Kit o Electronic Tool Kit o Micrometers o Calipers o Gages	5,000	-	5,000

12.3 DESIGN MARGINS SUMMARY

Positive margins of safety were found for all elements of the structural system of the MOD-5A wind turbine. The margins are often close to zero at locations in a substructure. Margin of safety (MS) to the allowable stress is defined in Volume II, section 9. A zero MS usually means that the predicted maximum stress is less than 67% of the stress that would cause permanent deformation or fracture or instability. In the case of fatigue, a zero MS usually means the predicted cyclic stress is below 67% of the cyclic stress that could initiate visible damage in 30 years.

A thorough analysis of the system's dynamic responses was discussed in volume II, section 7.0. The analysis predicted maximum loads and histograms of fatigue loads. The Structural Design Criteria, Volume II, section 9, required that design loads be adjusted upward from the predicted loads, based on comparison of predictions with measurements of loads on previous wind turbines and design maturity. The analytical stress levels were based on loads that were so adjusted and are compared to allowable stresses which are defined in the Structural Design Criteria (GE Spec 47A380002B).

The minimum margins of safety for comparing design stresses to allowable stresses are listed in Table 12-1. The "reference" column indicates the Volume III section of this report that contains a discussion of the analysis.

Table 12-1. Minimum Margins of Safety

Component	Design Stress (psi)	Condition	Margin	Vol. III Section Reference
Outer Blade				
Spar Shear	900	Limit	0.0	4.3.1.5.1
Skin	-3900	Buckling	0.0	
Spar Shear	181 ± 189	Fatigue	0.25	
Aileron Attachment				
Stud Force	57116	Limit	0.23	4.3.1.5.2
Stud Force	13000 ± 19000	Fatigue	0.0	
Aileron				
0.95 X/R, 0.6C	17000	Limit	0.59	4.4.2
0.95 X/R, 0.7C	-12000	Buckling	0	
30.95 X/R, 0.6C	6629 ± 7157	Fatigue	0.82	
Inner Blade				
Skin 0.3 X/R, 0.5C	4560	Limit	0.03	4.3.1
0.3C Spar Shear	182	Buckling	0.03	
Skin 0.3 X/R 0.6C	1200 ± 1100	Fatigue	0.01	
Center Blade				
At Bolster Tip	3300	Limit	0.24	4.3.1.1
At Bolster Tip	1405 ± 1320	Fatigue	0	
Bolster				
Cross Gain at Teeter Cup	286	Limit	0.14	4.3.1.1.1
Cross Gain at Brake	±235	Fatigue	0.4	4.3.1.2.1
Yoke				
Fwd Sheet Elbow	6000	Limit	4.0	4.5.2
Fwd Sheet Elbow	-4000 ± 5400	Fatigue	0.11+	
Teeter Brake Link				
Euler Column	11900	Stability	0.37+	4.5.5.1
Bearing Housing Max S_r	36000	Fatigue	0.25	
Low Speed Coupling and Shaft				
Friction Capacity (Ft-lb)	6.54×10^6	Limit	0.01	5.1.1
Shaft Fillet, mean ± rmc	5649 ± 777	Fatigue	0.03	

Table 12-1. Minimum Margins of Safety (Cont'd)

Component	Design Stress (psi)	Condition	Margin	Vol. III Section Reference
Gearbox Drivetrain				
	N/A	Limit	2.0	5.3
	20831	Fatigue	2.18	
Gearbox Housing				
	7289	Limit	3.12	5.3
	3000 ± 4000	Fatigue	0.43	
Rotor Support Bearings				
Retainer	89385	Limit	0.06	6.1.3
Retainer Max Stress Range	542	Fatigue	0.07	
Rotor Support Spindle				
Bolts to Adapter	65821	Limit	0.44	6.1.3
Flange Fillet	158	Fatigue	0.59	
Rotor Support Adapter				
Bolts to Bedplate, shear	38719	Limit	0.0	6.1.3
Radial Ribs	223	Fatigue	0.37	
Low Speed Brake Support				
Bolt Shear, No Preload	31388	Limit	0.71	4.5.7.1
Outer Web, max S_r	11894	Fatigue	0.09	4.5.7.1
Gearbox Mount				
Gearbox Footing Bolt	33900	Limit	0.04	6.1.4
Weld mean ± rmc	12900 ± 521	Fatigue	0	
Bedplate				
Webs, Fwd Section	26210	Limit	0.14	6.1.4
Web mean ± rmc	10200 ± 667	Fatigue	0.05	
Yaw Housing (Upper)				
Emergency Load	50000	Limit	0	7.5.1
Ribs, Max Stress Range	8400	Fatigue	0	
Yaw Bearing				
Support Row Hertz Stress	398000	Limit	0.45	7.5.2
Nose Ring, rmc	± 2711	Fatigue	0.75	7.5.2

Table 12-1. Minimum Margins of Safety (Cont'd)

Component	Design Stress (psi)	Condition	Margin	Vol. III Section Reference
Yaw Housing (Lower)				
Shell	30000	Limit	0	7.5.1
Ribs, Max Stress Range	9200	Fatigue	0.09	
Tower				
Seam at 627, Max Start/Stop	13108	Buckling	2.44	7.2.3
Seam at 627, 50% Overspeed	32770	Buckling	0.38	7.2.3
Seam at 627, RMC Stress	± 1433	Fatigue	0.12	7.2.3
Tower Door Region				
Seam at 137, 50% Overspeed	24426	Buckling	0.53	7.2.1
Top of Side Post, RMC	± 1060	Fatigue	0.06	
Foundation Attachment Bolts				
Extreme Wind	58500	Limit	0.2	7.4.5
RMC Stress	± 221	Fatigue	1.71	
Foundation (Preliminary)				
Concrete Shear, Extr Wind	116	Limit	0.02	7.4.4
Reinforcing Bar, S_r	20700	Fatigue	0.13	
Reinforcing Bar Welds	TBD	Fatigue	TBD	

12.4 QUALITY ASSURANCE AND INSPECTION REQUIREMENTS

The material in the following subsections describes the quality assurance measures, inspections and non-destructive evaluations which will be performed on the major assemblies of the wind turbine system to assurance the integrity of these assemblies before they are delivered to the assembly site.

12.4.1 TOWER

The material in the following sections is a summary of the quality assurance requirements for the MOD-5A tower. They are drawn from specifications and procurement documents which have been published and reviewed with the proposed suppliers.

12.4.1.1 Raw Material Control

The subcontractor will ensure that all raw material used in the fabrication of the tower is identified appropriately, by type, lot number, heat number or serial number. The subcontractor will comply with all drawings, specifications, procurement documents and Statements of Work pertaining to the wind turbine generator.

The subcontractor will obtain certifications of chemical and physical properties of all raw materials purchased from their suppliers for use on the tower. These certifications must be available for the customer to review at their convenience.

Material purchased and approved for use on the tower will be stored in a separate stock area and must be controlled carefully. Only material purchased and approved for use on the wind turbine generator may be used in the tower. Material that is not approved must be placed in a quarantine area and the customer must dispose of it. The use of unapproved material or material not purchased specifically for the wind turbine generator must be approved by the customer before it can be used in the tower.

The subcontractor will provide written certification that all material used in the tower conforms to specifications and that only material approved for its use has been used in the tower.

12.4.1.2 Certifications and Report Requirements

The subcontractor will provide, at the least, the following certifications and reports:

1. Written certifications of all the physical and chemical properties of all raw materials used in the tower. These may be mill test reports or test reports on samples of the material by an independent laboratory approved by the customer.

2. All welding will be done according to written weld procedures that adhere, in all respects, to the requirements of ANSI/AWS D1.1-82 and GE Specification 47A380054. Copies of all procedures and the applicable qualification data will be supplied to the customer. The subcontractor will pay particular attention to the requirements in Section 3 of GE Specification 47A380054.

3. All welding is to be done by welders who are qualified according to the requirements of ANSI/AWS D1.1-82. The subcontractor must maintain records of the qualifications and certifications of each welder and must provide copies of these records to the customer at the customer's request. Each welder must have a stamp or another means of identifying his work.

4. The subcontractor must maintain files of all radiographic, ultrasonic, magnetic particle and all other inspections and test data pertaining to the tower and its materials. These files must be available for the customer's review and approval. Reports summarizing this data must be submitted to the customer every month.

Hardware that does not conform to specifications, or hardware that has been reworked, will not be accepted without the customer's prior approval. Discrepancies between specifications and material or workmanship must be documented and reported to the customer immediately. The customer will determine how to dispose of the material. Reports of all discrepancies and the disposal of the materials must be submitted to the customer every month.

12.4.1.3 Factory and Field Inspection Requirements

12.4.1.3.1 Welding Inspector

The inspector will be responsible for verifying all matters pertaining to inspection and quality. They will be certified according to AWS-QC1 if this requirement is specified in the contract. Their duties will include, but are not limited to, the items in the following list.

A. Verification that all materials used in the tower satisfy all contract requirements.

B. Verification that all welding and joining processes are properly qualified according to AWS D1.1-82.

C. Verification that all welders and welding operators are duly certified to according AWS requirements.

D. Verification that all electrodes and filler materials meet the specifications.

E. Verification that the size, length and location of all welds are as shown on detail drawings.

F. To make sure that all welds are examined for size, contour, quality and workmanship.

G. Verification that welds conform to specifications regarding preheat and interpass temperatures, welding continuity, edge preparation, deburring and stress relief requirements.

H. Verification that all personnel performing non-destructive testing are qualified according to SNT-TC1A and the contract requirements.

I. Verification that any rework is done according to a qualified rework procedure that is approved by the customer.

12.4.1.3.2 Extent of Inspection or Test

The extent of inspection will be specified in the contract and the contractor will be required to perform these tasks:

A. The entire length of all welds will be visually inspected. Good lighting and magnifiers must be used for the inspection.

B. Magnetic particle testing will be performed on the entire length of the following welds:

   1. Fillet welds used to permanently attach fixtures, brackets, etc. to any portion of the tower.
   2. The affected area from which temporary attachment welds have been removed.
   3. Arc strikes on areas that are not covered by weld metal.

C. Radiographic tests will be performed on all longitudinal and circumferential welds on the tower. Radiographic tests will be performed on the entire length of all circumferential welds. Radiographs will be identified and kept on file for the customer's review.

   Longitudinal welds will be subjected to spot radiographic testing at all intersections with circumferential welds, for a minimum of 12 in. on each side of the intersection. If any of these tests show an unacceptable discontinuity, two additional tests, at least 4 in.

long, will be performed on the weld. If either of these tests show an unacceptable discontinuity, the entire length of the longitudinal weld in question will be tested radiographically. Discrepancies between the workmanship and the specifications will be documented. These documents, and the radiographs, will be filed and made available to the customer to review and approve.

D. Ultrasonic testing may not be used without prior written approval from the customer.

12.4.1.4 Non-Destructive Testing Acceptance and Rejection Criteria

Non-destructive testing on the tower will consist of visual, radiographic and magnetic particle tests. The types of non-destructive testing to be used on the various types of welds have been defined in a previous paragraph.

The limits on discrepancies between specifications and work and on discontinuities found in visual inspections are:

DISCREPANCY OR DISCONTINUITY	LIMITS
Undercut of parent metal adjacent to the weld,	Weld transverse to stress - .010 in., max Weld parallel to stress - .031 in., max
Scratch or burn marks resulting from striking arc	5% maximum reduction in parent metal thickness
Cracks in weld or in base metal	None allowed
Surface porosity	Dimension of greatest discontinuity: 1/8 in. Discontinuity not less than 3 times the greatest dimension of the defect from end of weld The space between two adjacent discontinuities must be greater than 3 times the greatest dimension of the larger discontinuity In a weld length equal to 6 times the weld size, the sum of the greatest dimensions of all voids must be less than the weld size. In a weld length less than 6 times the weld size, the sum must be proportionally less

DISCREPANCY OR DISCONTINUITY	LIMITS
Reinforcement	Reinforcement of butt joints must not exceed 1/8 in.
Overlap	None allowed
Convexity of fillet welds	Convexity may not exceed .07 times the face width of the weld, plus .06 in.

The limits for discrepancies between specifications and work and on discontinuities found during radiographic or magnetic particle testing will be the same as those for visual inspection, with these additions:

DISCREPANCY OR DISCONTINUITY	LIMITS
Sub-surface porosity	Dimension of greatest discontinuity: 1/8 in. Other criteria are the same as for surface porosity

12.4.2 NACELLE AND BEDPLATE

12.4.2.1 Vendor Selection Requirements

After preliminary bids are received, Procurement prepares a list of potential suppliers. Procurement checks the the customer's records for a supplier's performance record or quality history. If no records exist, representatives from Procurement, Manufacturing and Quality Assurance perform a pre-award or selection survey of the supplier's plant and quality system.

Procurement is concerned with the supplier's financial status, comparative prices and delivery record. Manufacturing reviews the supplier's facilities, equipment, engineering and production capability and experience with similar products. Quality Assurance audits the supplier's quality system, and observes the quality of work in progress, and the extent and effectiveness of process controls . This survey normally uses a prepared check list. The elements covered by the check list include:

- Procurement Controls
- Receiving Inspection
- Raw Materials Control
- Stock Room Controls
- Inspection
- Nonconforming Material Control

- Calibration System
- Drawing and Change Control
- Training and Certification
- Packaging and Shipping
- Inspection Stamps
- Special Processes
- Non-Destructive Testing

The check list requires details of each of these elements and yields valuable information on the supplier's quality system and its effectiveness. Based on the results of the survey, the supplier may be rated as qualified or unqualified. The supplier may also be given a conditionally qualified rating, which requires corrective action that will upgrade the quality system. If the corrective action is extensive, another survey may be required when it is completed.

The selection and approval of the supplier is the first step in controlling the quality of the products. GE's vendor quality assurance representatives periodically visit the plant to monitor and audit the vendor's conformance to the quality system. Checkpoints are established throughout the production cycle for GE's inspectors to witness the performance of inspections and tests. Performance and product quality are monitored closely and the supplier is rated relative to other suppliers.

12.4.2.2 Process Controls and Instructions

The subcontractor will prepare written specifications for the fabrication process procedures. These specifications must contain sufficiently detailed instructions to ensure the proper performance of each procedure, and to establish the controls necessary to ensure the quality of the product. A production flow chart, and a procedure specification for each critical element in the production flow will be submitted to GE for review and approval. At this time, GE will indicate the test or inspection points in the flow plan that will be witnessed.

Only materials specified on GE drawings will be used to fabricate the bedplate and the support structure elements. The material requirements are identified in the GE specification. This specification refers to the appropriate ASTM specifications for physical and chemical properties, tests, test data and mill test reports, and certifications that the subcontractor must obtain and maintain on file.

The subcontractor will provide documents of the following:

- The materials ordered and received are correct and satisfy GE requirements,
- Appropriate mill test reports and certifications of physical and chemical properties have been received and filed,
- Materials are identified with the appropriate lot, heat, slab and serial numbers,
- Records of heat treatment times and temperatures,
- Records of ultrasonic inspection, according to GE specifications and ASTM A578 have been received and filed.
- Results of impact testing for all temperature levels specified in the GE specification and in references to ASTM A673.

All welding will be done to written welding procedure specifications. All welding must be done by welders certified to perform that type of welding. Weld procedure specifications must provide detailed instructions on all of the following:

- Base metal
- Filler or electrode metal
- Type and polarity of current
- Backing material, if required
- Flux, if required
- Shielding gas, if required
- Material thickness range
- Weld positions
- Preheat temperature requirements
- Interpass temperature requirements
- Post weld heat treatment requirements
- Ambient temperature limitations
- Preparation of edges of base material
- Technique to be used
- Number of passes required
- Appearance of welding layers
- Cleaning between passes and of finished weld
- Procedure and performance qualification records
- Operator qualifications.
- Certification records.

12.4.2.3 Non-destructive Test and Inspection Requirements

Non-destructive testing of the bedplate and other major structural components will consist of visual, dye penetrant, magnetic particle, radiographic and ultrasonic tests. The tests are defined as:

- Visual - All welds will be inspected visually over 100% of the length. Good lighting and the use of magnifiers are recommended.
- Dye penetrant - Dye penetrant inspection is not mandatory, but it may be used to improve the effectiveness of visual inspection, particularly when the possibility of microscopic surface cracks exists.
- Magnetic particle - All welds must be inspected by the dry powder magnetic particle method, over 100% of the length, according to Section 6.7.5 of ANSI/AWS D1.1-82.
- Radiographic and ultrasonic - All full penetration welds, unless otherwise noted on a GE drawing, will be inspected radiographically or ultrasonically over 100% of the length. Radiographic inspections must be performed according to ANSI/AWS D1.1-82, Part B of Section 6. Ultrasonic inspections must be performed according to ANSI/AWS D1.1-82, Part C, of Section 6. Radiographic inspection is preferred.

The acceptance or rejection criteria for non-destruction testing are:

12.4.2.3.1 Visual and Dye Penetrant Inspection

CRITERIA	LIMITS
Maximum undercut of parent metal adjacent to the weld	Weld transverse to stress: .010 in., max Weld parallel to stress: .031 in., max
Scratch or burn marks (Resulting from striking arc)	Maximum of 5% reduction in parent metal thickness
Cracks in weld or in base metal	None allowed
Surface porosity	Dimension of the largest discontinuity: 3/32 in. Discontinuity not less than 3 times the largest dimension from the end of the weld

CRITERIA	LIMITS
	Space between two adjacent discontinuities not less than 3 times the largest dimension of the larger one
	In a weld length equal to 6 times the weld size, the sum of the largest dimensions of all voids will be less than the weld size. In a weld length less than 6 times weld size, the sum will be proportionally less.
	For discontinuities whose greatest dimension is less than 3/32 in., the sum of their greatest dimensions may not exceed .25 in. in any linear inch of weld.
Reinforcement	Reinforcement of butt joints will not exceed 1/8 in.
Overlap	None allowed
Convexity of fillet welds	Will not exceed .07 times the actual face width of weld, plus .06 in.

12.4.2.3.2 Magnetic Particle or Radiographic Inspection

The acceptance or rejection criteria for radiographic or magnetic particle testing are the same as those for visual inspection with the additions:

CRITERIA	LIMITS
Sub-surface porosity	Dimension of the largest discontinuity - 3/32 in.

12.4.2.3.3 Ultrasonic Inspection

The acceptance and rejection criteria for ultrasonic testing will be in accordance with ANSI/AWS D1.1-82, Section 9.25.3, Table 9.25.3 for tension welds. Non-fatigue critical welds may be inspected in accordance with ANSI/AWS D1.1-82, Section 8.15.3, if this is allowed by the GE drawing.

12.4.2.4 Data Requirements

12.4.2.4.1 Raw Materials Data

The following data and certifications must be supplied for all materials used in the bedplate and major structures:

ASTM A572, Grade 42 or Grade 50

- Mill test reports listing physical and chemical properties of the material. Materials are to be identified by lot or heat numbers and slab or serial numbers so that the materials can be correlated with the test data supplied by the mill. Independent laboratory analyses may be used instead of mill test reports, provided the GE has approved of the independent laboratory.
- Reports of ultrasonic testing of plate material per ASTM A578.
- Impact test data at +10°F and at -40°F per ASTM A673.
- Results of impact and tensile testing at 70°F on coupons that were previously heat-treated at 1150°F for 12 hours.
- Copies of all furnace tapes indicating temperatures and times for all normalizing and heat treating specified by the GE must be supplied.

ASTM A633, Grade C

- Mill test reports, listing the chemical and physical properties of the material. The material must be identified so that it can be traced to the appropriate mill test report. Independent laboratory analyses of coupons or samples may be substituted for mill test reports, provided the GE has approved of the independent laboratory.
- Results of impact testing in both the longitudinal and transverse directions at +40°F on material normalized per ASTM A673.
- Results of ultrasonic testing of plate material per ASTM A578, including S2.
- Impact test data, establishing a temperature-absorbed energy curve. The range of test temperatures must be wide enough to establish the upper and lower shelf energies. The testing at intermediate temperatures must permit a reasonably smooth curve to be plotted.

12.4.2.4.2 Welding Procedure Qualification Data

Copies of welding procedure qualification records, indicating process type, material type, thickness range qualified, filler metal type, current type, electrode, etc. must be supplied to GE. The record must include tensile and bend test descriptions and data, and must list the complete impact test data for all impact specimens.

12.4.2.4.3 Welder or Operator Qualification Data

The data required for the procedure qualification is also required for the welder qualification. The record must identify the procedure, material, thickness range, filler metal, etc. The record must also identify the welder who prepared the test samples for qualification. A qualification record is required for each welder and for each process.

12.4.2.4.4 Non-Destructive Test Data

Non-destructive test data specified in GE drawings and specifications must be supplied to GE. In addition, qualification records of workers and supervisors performing non-destructive tests must be supplied.

12.4.3 GENERATOR AND MAJOR ELECTRICAL COMPONENTS

12.4.3.1 Generator Subsystem Inspection and Acceptance Plan

The generator subsystem is a 7,500 kVA variable speed power generating subsystem, consisting of a wound rotor generator, a cycloconverter, a cycloconverter control unit, an isolation transformer and accessories. Each element of the subsystem must satisfy the operating characteristics and conform to the mechanical and electrical interfaces specified in GE drawing 47A380094 and applicable drawings.

The supplier will provide GE with the data required by the tables in drawing 47A380094, which list the parameters for each subsystem element, within ten weeks after the order is received. The supplier will submit, at the same time, a design, manufacturing and test flow plan indicating the basic design operations, manufacturing operations, reviews and production tests and inspections to be performed on each element. GE will establish from the flow plan the tests and inspections that a representative will review and witness. The supplier must notify GE at least 48 hours before the tests or inspections are to be conducted. All testing must be performed to detailed, written test procedures prepared by the supplier and submitted to GE for approval. Testing may not commence until the procedures have been approved.

The components of the subsystem will be subjected to at least the following production tests and inspections:

12.4.3.1.1 Generator

- o High potential test
- o Insulation resistance test
- o No load loss measurement (motor conditions)

- Phase sequence
- Wiring continuity
- Wiring conformance to diagrams
- Dimensional checks
- Visual checks for finish, workmanship, etc.

12.4.3.1.2 Cycloconverter

- Wiring insulation resistance tests
- Wiring continuity
- Wiring conformance to diagrams
- Control functional checks
- Dimensional checks
- Visual checks for finish, workmanship, completeness, etc.

12.4.3.1.3 Isolation Transformer

- High potential test
- Insulation resistance test
- Ratio checks
- Connection continuity
- Wiring conformance to diagrams
- Visual checks for finish, workmanship, completeness, etc.

12.4.3.2 Test Plan

A subsystem test will be performed on the first hardware at the supplier's plant that satisfies requirements. The test will obtain data on the subsystem's operation, calibrate sensors and identify any potential problems that would require that the unit be modified and adjusted. The subsystem will be instrumented to sense and record performance parameters.

A detailed, written test plan and schedule will be prepared by the supplier and approved by GE before the tests begin. This plan will cover the following functions, at least:

- Motoring mode
- Synchronization at various accelerations and speeds.
- Torque regulation at various accelerations and speeds.
- VAR regulation at various accelerations and speeds.
- Calibration of transducers
- Generator bearing operation at 7° incline.
- Harmonic current measurement at various speeds and converter power levels.
- Measurement of lubrication and air cooling flow and temperatures.
- Shutdown on loss of power.

12.4.4 GEARBOX

12.4.4.1 Description

The speed increaser gearbox is a three-stage unit with epicyclic first and second stages and a parallel shaft third stage. The input to the gearbox from the rotor will be in the range of 12 to 17 rpm with 13.7 and 16.8 rpm considered as the rated input speeds. The output of the gearbox drives the variable speed generator subsystem. The gearbox must satisfy all the requirements of GE specification 47A380083 and applicable GE drawings.

12.4.4.2 Documentation

The supplier will provide GE with a manufacturing and test flow plan showing the basic manufacturing operations, reviews, special processes and production inspections and tests. GE will establish from this flow plan the tests and inspections that a representative will review and witness. The supplier must notify GE at least 48 hours before these tests or inspections are to be conducted.

12.4.4.3 Tests

The completed gearbox will be subjected to a series of functional and operational tests at the supplier's plant to show that the unit satisfies specifications and to identify potential problems that may require that the unit be modified and adjusted. These tests include, but are not limited to:

- a four-hour, no-load, run-in test at rated speed,
- measurement of breakaway torque, and
- no-load loss measurement.

The supplier will prepare a detailed, written test plan describing the tests to be performed. The plan must be submitted to GE for approval. Testing may not commence until GE has approved the test plan. The supplier will record all operating test times and conditions of operation, such as speed and load.

12.4.4.4 Test Plans and Test Data

The supplier will submit all operating test data to GE for review and approval. The supplier will also supply copies of all data and certifications pertaining to materials used in the production of the gearbox. Mill test reports, physical and chemical data records, furnace tapes showing times and temperatures for all heat treating and stress relieving operations. Non-destructive test reports and any similar data must be supplied to GE.

12.4.5 BLADE

12.4.5.1 Vendor Manufacturing Controls and Surveillance Instructions, Blade

The requirements to be used by the supplier to control raw materials and to control the blade fabrication process are detailed in GE document 47A380074. A copy of this document is included in the appendix of this volume. The supplier needs to incorporate these requirements into the process specifications and instructions. After the instructions have been reviewed and approved, Quality Assurance representatives will make periodic visits to the supplier's plant to verify that the controls are implemented, are followed, and that the desired results are achieved.

12.5 FINGER JOINT PROCESS DEVELOPMENT UNIT

12.5.1 FINGER JOINT PROCESS DEVELOPMENT UNIT (FJPDU) INSPECTION REPORT.

The finger joint process development unit is described in section 8.2.1 in Volume II of this report. It is a full size, short center blade section made in two pieces with machined finger joints and partial reinforced wood.

During the machining of Module 2-M, the finger locations were shifted by 1.218 in. from their true location, because of a discrepancy in the machine set-up. To compensate for this shift, and to insure proper fit, an equivalent shift was made during the machining of Module 1-M. In addition to the shift, there were additional errors, ranging from .011 in. to .161 in. on certain fingers of Module 2-M, and from .011 in. to .102 in. on fingers of Module 1-M. As a result, tooth misalignment between Modules 1-M and 2M ranged from .004 in. to .066 in. These discrepancies were documented in NCR AE-1099. The result will be that the width of the bond gap will not be uniform when the modules are bonded together.

After the modules were shipped to Gougeon Brothers, Inc. (GBI), a trial fitting was performed. One-eighth in. thick shims were placed between the fingers at each end at the top and bottom of the module. Previous experience with sample pieces showed that when pieces are mated, even when they are dry, it is very difficult to separate them again. After closing up tight to the shims, the bonds were examined for any obvious interference between fingers. Some of the bond gaps were not uniform, but there were no obvious interferences, confirming this data. So long as controlling bond gaps are greater than about .070 in., there should not be any interference in the fit.

The units were mated and bonded February 22, 1984. Observers from GBI, GE and NASA were present. GBI made many trial and training runs with the modules and with fixtures that simulated the finger joints. The actual bonding progressed smoothly, and was completed in just under two hours. Some minor problems were encountered with the wands used to spread the thickened epoxy, but those would be corrected prior to blade fabrication.

Some misalignment was observed after the mating. One side was approximately .080 in. farther from full mating than the other side. Attempts to pull this end in closer, using come-alongs, were not successful, because the epoxy had begun to set. The following day, the excess epoxy was cleared from a few small areas to examine the bond gaps. There was a lot of variation in the bond gaps, and in some areas the gaps were larger than design values.

GBI was instructed to clean excess epoxy from the entire joint and to photograph the bond gaps at intervals.

When the test samples are cut from the modules, the bond gaps can be measured. The effect of gap size on test results can be evaluated from these measurements.

12.5.2 NON-DESTRUCTIVE TESTS FOR VERIFYING FINGER JOINT INTEGRITY

Bonding the blade sections is one of the most important operations in the fabrication of the wind turbine generator. These bonds are called finger joints because of their appearance and the way they fit together. The ends of the blade sections must be accurately machined so that they fit together properly. The blade sections must be properly aligned as they are bonded. The bond gap must be uniform around the joint. The resin and hardener must be mixed to exact specifications. The mixed bonding agent must be applied uniformly to the faces of all the fingers. The fingers must be properly cleaned so that there are no contaminates in the epoxy to cause defects in the bond. Above all, voids caused by trapped air must be minimized. Most of these potential problems can be eliminated by strict process control. Because these joints are so important to the success of the wind turbine, some method of checking the finished joint for voids in the bond gap is required.

A review of current non-destructive testing techniques indicates that radiographic and ultrasonic testing are the most suitable techniques for this application. Both methods have been used with some success in detecting flaws in fiber-reinforced composites and laminae. Both methods have located and identified voids and inclusions. Ultrasonic tests detect fiber breaks and uncured resins, but do not distinguish small delaminations, voids and resin cracks. Radiographic tests detect delaminations easily. Therefore, both methods should be used. Together, the tests provide an accurate indication of the quality of the finger joints. Since very little data is available on the use of these methods with laminated wood and epoxy, some experimental work would be necessary to build up a data base for the evaluation of the test results.

12.5.3 INSPECTION AND TEST PROCEDURES FOR LOCATING VOIDS, FLAWS AND DELAMINATIONS IN BLADE SECTIONS

12.5.3.1 General Description

The inspection and test methods for locating voids, flaws, delaminations and other defects in blade sections are discussed in this section.

When composite materials were first introduced, non-destructive testing technology was not prepared to handle many of the problems presented by composite materials. Relative densities of materials, the use of non-conductive materials, material thicknesses and other considerations tended to make conventional non-destructive tests, such as X-ray, magnetic methods and ultrasonics, relatively useless. Now equipment and methods are available for locating and evaluating voids, delaminations, inclusions, incorrect layering and other defects. Most of these methods, however, are very expensive and, in most cases, a combination of techniques is required to identify and assess the defects properly. The extent of testing, therefore, is affected by available technologies, and by its impact on the cost of the finished product.

The three most useful techniques for non-destructive testing of composites or laminae, are radiography, ultrasonics and acoustic emission. A brief discussion of the advantages and disadvantages of each method follows. The opinion of the industry is that no one technique adequately detects and evaluates flaws in composite materials.

12.5.3.2 Radiography

In this technique, penetrating radiation is used to examine the material or object. Relative transmission or attenuation of the radiation is used to evaluate the internal structure of the object. Radiography requires access to both sides of the object. Sensitive film is exposed to the radiation as it passes through the object. The degree of exposure is a function of how much attenuation has taken place within the object. Successive exposures from different angles provide enough information to estimate the size and location of defects, such as cracks, porosity, voids and inclusions. Generally, discontinuities with dimensions equal to 2% of the object's thickness can be detected reliably. Cracks must be parallel to the radiation beam to be detected.

There are two types of beams used in radiography, X-ray and gamma-ray beams. Each has advantages and disadvantages. Gamma-rays penetrate much deeper than X-rays. X-ray equipment is generally bulky, not movable and very expensive, but gamma-ray equipment, is generally small and portable. Voltage, exposure time and focal point size are very important for X-ray tests. Handling and locating the radioactive isotope source that supplies the gamma-rays frequently presents problems. Both methods pose potentially serious health hazards to the operators. To be reliable, a data base on transmission and attenuation characteristics of the materials must be generated. A certain amount of development testing would be required before these methods could be used in production.

12.5.3.3 Ultrasonics

There are two methods generally used in ultrasonic testing, the pulse echo technique and the through transmission technique. In the pulse echo method, sound energy is reflected from flaws and from the back of the material. The echos are detected on the same side of the object as the energy source. In the through method, sound energy is detected on the side of the object opposite the source, so access to both sides of the object is required. Both methods use sound waves in the range of 20,000 to 20,000,000 Hz. The waves are generated by piezoelectric transducers. The best results are obtained when some type of couplant, usually a fluid, transfers energy from the transducer to the object. Ultrasonic signals suffer very little attenuation in passing through the test object, therefore, they can penetrate very thick objects. The signals, unlike X-rays, pose no health hazard to operators.

The wave motion induced in the test object by the transducer may be either longitudinal or transverse. Longitudinal or compression waves induce oscillation parallel to the direction of the wave propagation. Longitudinal waves travel at high velocities and can be focused in narrow beams. Narrow beams can locate and determine the size of a defect precisely. Transverse or shear waves induce oscillation perpendicular to the direction of wave propagation. Transverse waves travel at lower speeds than longitudinal waves and are more easily scattered. The lower speed makes the wave more sensitive to small defects.

The sensitivity of ultrasonics and radiography are comparable. Ultrasonic equipment is portable and can be automated. Good, permanent records are hard to keep. Traces may be photographed, or the electrical impulses may be recorded on magnetic tape or on strip chart recorders. Correlating these records with the tested area is a problem. Ultrasonic tests require reference standards and a well-trained, skilled operator for a reliable interpretation of the signals. Ultrasonic tests are difficult on thin or complex parts, and erroneous indications are likely on coarsely grained materials. Ultrasonic testing also requires development testing to develop a data base for the materials under test.

12.5.3.4 Acoustic Emission

In this method, a load of some type is applied to the object under test. Elastic stress waves are produced by flaws in the loaded object. Each flaw produces a unique stress wave. In composites, stress waves are generated by broken fibers, cracks in the bonding material or matrix, separation of fibers from the matrix, poor bonding between laminae, and improperly cured bonding materials. Transducers mounted at strategic locations on the object permit monitoring from a remote location. An incipient failure may be detected by monitoring the stress waves produced by a growing defect. The technique is relatively simple to implement and the equipment required is not expensive.

The article is loaded initially to establish a calibration point or benchmark. Some development testing would be required to establish the emission characteristics for various types of flaws in the materials used in the blades. Acoustic emission would probably be the best test method, since it would provide useful data not only during manufacturing and testing, but for the entire life of the blades.

13.0 FMEA/RAM/MAINTENANCE

13.0 FMEA, RAM, AND MAINTENANCE

13.1 INTRODUCTION AND SUMMARY

As a third-generation design for application in the utility power industry, the MOD-5A wind turbine generator is expected to have the maturity of design that provides a significant growth in reliability over that of its first and second generation predecessors, the MOD-0A, MOD-1, MOD-2. Operational experience was factored into the MOD-5A design, to improve the reliability, availability, and maintainability (RAM). The RAM analysis focused on recent design changes and provided documented assurance that the MOD-5A is a mature design.

In terms of reliability, experience guided the MOD-5A design toward changes that provided more acceptable risks. Critical and potentially catastrophic failures that could be attributed to design deficiencies and human errors in manufacturing, inspection, and the maintenance of components were observed on operational wind turbines. Components must be designed and built to last the life of the system. Observations of failures on other wind turbines also suggest that appropriate control and protection requirements dealing with the external and operational stress environments may be more complex than was assumed in earlier designs. These conclusions indicate that innovative or redundant designs of structural components, and an effective Safety and Control System that reduces the technical risks and increases the operational reliability and availability are required.

The purpose of the documentation of the failure modes and effects analysis (FMEA) is to demonstrate that all potential failure modes and effects were identified and that design and maintenance provisions satisfied the safety, maintenance, and operational requirements of the MOD-5A wind turbine. Design engineers continue to update the FMEA, to guarantee that all parts of the design were considered and that the effects of design changes are properly evaluated, to minimize risk and increase reliability.

The major design changes and innovations in the final MOD-5A design, model 304.2, include:

- A Multiple-Section Aileron Control System: to alleviate critical blade design loads and weights associated with a partial span control system.

- A Non-rotating Rotor Support Shaft: to eliminate reverse bending fatigue, to reduce the design requirements, and to provide redundant load paths for major rotor support and torque structures (the low speed shaft, yoke and main bearing).

- A Variable Speed Generator: to reduce the design loads and drivetrain requirements, to provide greater operational flexibility, and to provide controlled drivetrain softness and damping.

- A Redesign in the Blade Planform: to accommodate more conservative design allowables for the blade material without penalizing the performance.

- A More Effective Safety and Control System Design: to discriminate between critical and non-critical failures and minimize unnecessary shutdowns, to improve diagnostics and maintainability, and to increase operational availability and safety.

Each of these changes were part of the effort to minimize technical risk and to improve the reliability, safety, and maintainability of components. Subsystem trade-offs between complex and simple designs and between reliability and maintainability were evaluated in the RAM study, to find designs with high availability and low risk. The results of the RAM analyses, shown in Table 13-1, project the following:

1. Increases in key subsystem reliability, with a corresponding decrease in the predictable failure rates.

2. A reduction in the technical risks associated with unpredictable structural failures, based on operational experience with first and second generation wind turbines.

3. Increased reliability, as a result of improved designs of critical operational functions.

4. A decrease in the system's mean time to repair (MTTR), as a result of changes that increase equipment maintainability and the wind turbine's availability.

5. The use of a complex design for the power generation, and control and instrumentation systems, to improve performance, failure diagnostics, and safety provisions and to reduce the MTTR and average annual outage (AAO) time.

The operational characteristics and design requirements for the control of a wind turbine generator dictate a level of sophistication in power generation and control systems that are not normally encountered in mature utility power systems. Complexity is a positive attribute if it characterizes a system or

Table 13-1

MOD-5A RAM Update and Summary

	1982 ESTIMATES				FINAL ESTIMATES				COMMENTS
	FPY	MTBF	MTTR	AAO	FPY	MTBF	MTTR	AAO	(Major Contributors)
Yoke	0.47	18,638	61	28.6	0.46	19,043	44	20.2	o Design change includes rotor bearings/teeter mech.
Aileron Control	0.60	14,600	24	14.4	0.60	14,600	24	14.4	o Ailerons, Bearings, Hinges
Blades	0.07	130,750	254	17.0	0.07	130,750	254	17.0	o Primarily Fatigue cracks
Drivetrain	1.59	5,500	39	62.3	0.66	13,270	38	25.0	o Simpler system, Gearbox
Hydraulics	3.27	2,680	12	38.7	2.85	3,074	15	43.1	o Ailerons, Teeter, Yaw Systems
Yaw Mechanism	.09	97,000	177	16.0	.09	97,000	177	15.9	o Yaw Bearing/Drive Mech.
Tower/Nacelle	.35	25,000	60	21.0	.05	175,200	4	0.2	o Non-critical failures excluded
Controls	4.87	1,800	8	38.3	4.44	1,972	6	25.4	o With shutdown discrimination and increased complexity
Power Generator	0.10	87,600	48	4.8	2.74	3,197	10	27.8	o Change to variable speed (maintainability)
SYSTEM TOTALS	11.41	768	21	241.1	11.96	732	16	189.0	
AVAILABILITY (W/O SM)	.972				.978				$A = \frac{8760 - AAO}{8760}$
AVAILABILITY (W/SM = 90 HRS)	.962				.968				$A = \frac{8760 - AAO - SM}{8760}$

subsystem design that fails in a safe, benign manner, with appropriate diagnostics that minimize the mean time to repair and average outage time.

Utilities increased their emphasis on reliability and operational availability of power generation equipment at all levels, because of the effects of forced outages on lost revenue. A third generation wind turbine design must address the issue of potential outage time to be acceptable to the utility industry. This RAM study and the design changes in the MOD-5A wind turbine indicate an improvement in the reliability of critical components and in the predicted forced outage time, over the preliminary MOD-5A and the first and second generation wind turbines.

13.2 FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

13.2.1 INTRODUCTION

13.2.1.1 Purpose

The purpose of the FMEA is to identify the potential failure modes that could lead to a catastrophic failure if uncontrolled, undetected, or uncorrected. A catastrophic failure is one that results in a serious injury or the loss of a major wind turbine component. This analysis identifies all the plausible failure modes and their effects and provides means of avoiding them through appropriate designs and maintenance provisions. The identification and documentation of a failure mode and its effects indicates deficiencies in the design of a component or subassembly. Corrective action is required.

13.2.1.2 Scope

The FMEA analysis covers each system, subsystem, subassembly and component of the MOD-5A wind turbine. It includes all credible single point failure modes and the effects on the operation, maintenance, and safety of the machine. This FMEA does not consider multiple or contributing failure modes, because they were accounted for by design engineers who studied the next level of effects and requirements associated with failsafe electronics, redundant and failsafe shutdown modes, redundant structures and load paths, redundant electrical power systems and protection devices, and redundant control sensors.

The FMEA emphasized design considerations for automatic and manual failsafe operation in all modes, long term aging, durability, and corrosion effects on component reliability, and appropriate economic, maintenance, and safety design requirements.

13.2.1.3 Background

Contractual design requirements and specifications from NASA and DOE in the development of the MOD-5A wind turbine generator are detailed in the Statement of Work, DEN 3-153, dated April 2, 1982. The statement of work calls for "unattended, fully automatic, failsafe MOD-5A operation" and for the requirement that "any one failure or malfunction shall not create a hazardous or catastrophic condition for MOD-5A equipment or personnel".

In addition to the operational control and safety requirements on the wind turbine's reliability, the economic goals or requirements for operational availability, reliability, and maintenance of hardware must also be met. An effective operational control and safety system could significantly limit the wind turbine's operation, energy production, and cost effectiveness. The ideal design is a compromise between the operational control and safety requirements, and the maximum operational availability, which limits unnecessary shutdowns, lockouts, and maintenance.

13.2.2 FMEA TASK APPROACH AND PROCEDURES

13.2.2.1 Task Approach

Each component must be evaluated for any single point failure modes. All components and subassemblies, were listed by function, to identify the potential failure modes and effects. This list was updated throughout each design phase to eliminate or reduce any catastrophic single point failures. Beginning with top-level hazards analysis in conceptual design, the FMEA grew and extended to the lowest level of system definition.

13.2.2.2 Definition of Terms

System - The major functional divisions of MOD-5A components and subassemblies are generally the level of responsibility of design engineers.

Subsystem - The first subdivision in an individual system, relating to the functional interface and assembly of components.

Component - The lowest level of a system for which the failure modes and effects are identified and evaluated. An FMEA worksheet is assigned to each component and is identifiable by an applicable drawing number and FMEA number.

FMEA Number - A number assigned to the worksheet that identified the system, subsystem, and functional sequence of the component.

Function of Component - A statement of the primary function of the component.

Failure Modes and Effects - Identification of all component failure modes and effects in order of severity, and depending on the operational mode.

Applicable Operating Modes -

A. Generating
B. Start-up
C. Normal Shutdown
D. Emergency Shutdown
E. Lockout
F. Stand-by - Enable/Operational
G. Stand-by - Inhibit/Maintenance

Severity of Failure Modes - The four categories of severity are defined as follows:

Catastrophic - a failure resulting in serious injury to or death of workers, or that requires the replacement of a major component that costs over 20% of the MOD-5A's capital cost.

Critical - a failure that could lead to serious injury or a catastrophic failure.

Marginal - a failure that results in shutdown, lockout, or that inhibits start-up, and that could cause minor injury or minor damage to the system or utility.

Minimal - a failure not serious enough to cause injury, damage property or the system, and that could be repaired when convenient or during scheduled maintenance.

Failure Detection Methods - The means by which a failure mode is automatically detected in unattended, failsafe operation.

Failure Cause and Compensating Provisions - For each failure mode, there is a cause or combination of causes relating to environmental conditions, loading, fatigue, wear, corrosion, etc. The definition of probable causes leads to the description of compensating design and maintenance provisions that may reduce the criticality and probability of failure.

13.2.2.3 FMEA Procedures

The FMEA worksheets are prepared in design, and continually updated by design engineers with design changes, test results, and operational experience. Each component failure is considered the only failure in the system when evaluating the effects and causes of the failure. When the failure mode is considered to be non-detectable, the evaluation is extended to determine the effects of a second or higher level failure with the worst effect. For example, undetected fatigue cracks, as a structural failure, could result in the eventual loss of the component, with potentially catastrophic effects. The requirements for detection methods and for provisions to compensate for the design deficiency are determined with the identification of a failure mode and the evaluation of its effects and causes.

The procedure for updating the worksheets aims to eliminate all single point failure modes that could lead to a critical or catastrophic failure. Any information, such as test results, that could support that conclusion is listed in the FMEA worksheets. Undetected structural failures remain the most obvious and potentially most catastrophic of all the failure modes. In most cases of structural failures, there are no fully automatic means to detect faults, other than vibration sensors. Therefore, all the dynamic load profiles must be thoroughly evaluated and tested and adequate allowable stresses and safety margins must be defined in design, to minimize potential failures. Also, periodic inspection must be considered for avoiding catastrophic structural failures, but by definition the method of detecting faults cannot be considered automatic.

Comments and remarks are included in the FMEA worksheet, so the design engineer can provide information that could support the conclusions about the reliability, safety and maintainability of the component or subassembly.

13.2.3 RESULTS AND CONCLUSIONS

The FMEA indicates that the effort to establish high reliability and safety standards for the MOD-5A design was appropriately addressed in the final design phase. The results and conclusions of the analysis include the following:

1. The FMEA identified all plausible failure modes, effects, and causes and defined the detection methods and adequate provisions for avoiding catastrophic, single point failures.
2. The FMEA addressed all wind turbine operating modes to assure that no failure could go uncontrolled, undetected, or uncorrected.
3. The FMEA addressed the experience gained from the failure modes of first and second generation wind turbines in the design of the MOD-5A.
4. The FMEA was extended to the lowest level of the system of both the functional and physical aspects of series-connected components and subassemblies, including interface failures.
5. Requirements for functional and hardware redundancy at all indentured levels of systems and subsystems were identified and implemented to protect major components and subsystems.
6. Provisions to eliminate hazards to the safety of the public and installation and maintenance personnel were addressed to the component failure level.

Examples of the provisions that avoid, or compensate for failures arising from the FMEA and implemented by the design engineers include the following:

1. Requirements for failure detection: sensors, alarms, automatic shutdown logic and response.
2. Requirements for periodic or immediate inspection and maintenance.
3. Requirements for redundant components, structural load paths, controls, and shutdown modes.
4. Requirements to protect against the effects of the environment, such as icing, corrosion, temperature, and moisture.
5. Requirements for protection against hazards to the safety of the workers and the public.
6. Requirements for component tests that verify design criteria and material and component specifications.
7. The elimination of electrical and control system interface design deficiencies that induced emergency shutdown when normal shutdowns or warnings were adequate.

13.2.4 SAMPLE FMEA WORKSHEETS

The FMEA is completely documented in GE Cont. Doc. No. 47A380049, Rev. F. It covers the major subsystems, assemblies, 34 subsystems, and 306 functional components. An FMEA worksheet is provided for each component by the systems engineers. The worksheets are organized systematically depending on the functional relationship and, more importantly, the areas of design responsibility. Typical FMEA worksheets are shown in Figures 13-1 and 13-2.

13.3 RELIABILITY ANALYSIS

13.3.1 INTRODUCTION

The RAM analyses are predictions, based on statistical data, used for evaluating the design and the operational requirements and cost effectiveness of the MOD-5A, as a commercially feasible power generation system. The documentation of the MOD-5A RAM analyses is significant from three standpoints. It focuses attention on the design requirement to meet short and long-term goals. It shows the growth of maturity compared with first and second generation machines. Most importantly, it establishes the credibility of the MOD-5A design.

The development of large utility-class wind turbines has been actively pursued in the last ten years in the United States. Feasibility and demonstration projects sponsored by DOE and NASA showed that wind turbines are feasible, to the extent of attracting a significant amount of interest and venture capital from utilities. The projected economic goals and performance predictions are important to the development and commercialization of large wind turbines.

The RAM analyses on the MOD-5A and comparable wind turbines is handicapped by the lack of reliability data for various components. Analysis of some components, such as electrical and electronic equipment, hydraulic equipment, and control system equipment and sensors are applicable in similar operational and stress environments. Others must be extrapolated to provide predictions of life, failure rates, dependability, and repairability.

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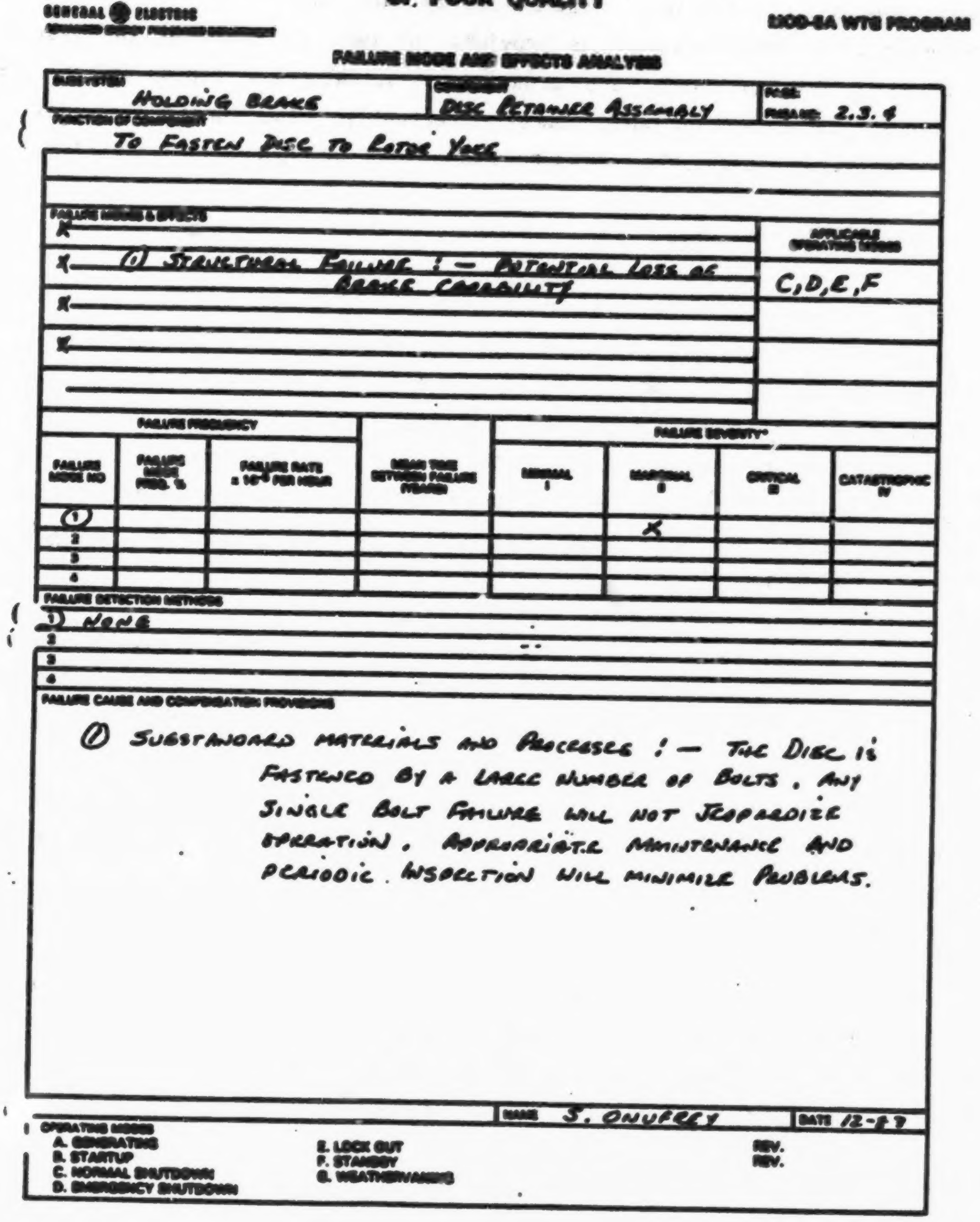

GENERAL ELECTRIC
ADVANCED ENERGY PROGRAMS DEPARTMENT

MOD-5A WTG PROGRAM

FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM: HOLDING BRAKE

COMPONENT: DISC RETAINER ASSEMBLY

PAGE:

FMEA NO: 2.3.4

FUNCTION OF COMPONENT: TO FASTEN DISC TO ROTOR YOKE

FAILURE MODES & EFFECTS

X (1) STRUCTURAL FAILURE : — POTENTIAL LOSS OF BRAKE CAPABILITY

APPLICABLE OPERATING MODES: C, D, E, F

FAILURE FREQUENCY			MEAN TIME BETWEEN FAILURE (YEARS)	FAILURE SEVERITY*			
FAILURE MODE NO	FAILURE MODE FREQ. %	FAILURE RATE x 10^{-6} PER HOUR		MINIMAL I	MARGINAL II	CRITICAL III	CATASTROPHIC IV
①					X		
2							
3							
4							

FAILURE DETECTION METHODS

1) NONE
2
3
4

FAILURE CAUSE AND COMPENSATION PROVISIONS

① SUBSTANDARD MATERIALS AND PROCESSES : — THE DISC IS FASTENED BY A LARGE NUMBER OF BOLTS. ANY SINGLE BOLT FAILURE WILL NOT JEOPARDIZE OPERATION. APPROPRIATE MAINTENANCE AND PERIODIC INSPECTION WILL MINIMIZE PROBLEMS.

NAME S. ONUFREY

DATE 12-8[illegible]

OPERATING MODES
A. GENERATING
B. STARTUP
C. NORMAL SHUTDOWN
D. EMERGENCY SHUTDOWN
E. LOCK OUT
F. STANDBY
G. WEATHERVANING

REV.
REV.

Figure 13-1 Typical FMEA Sheet #1

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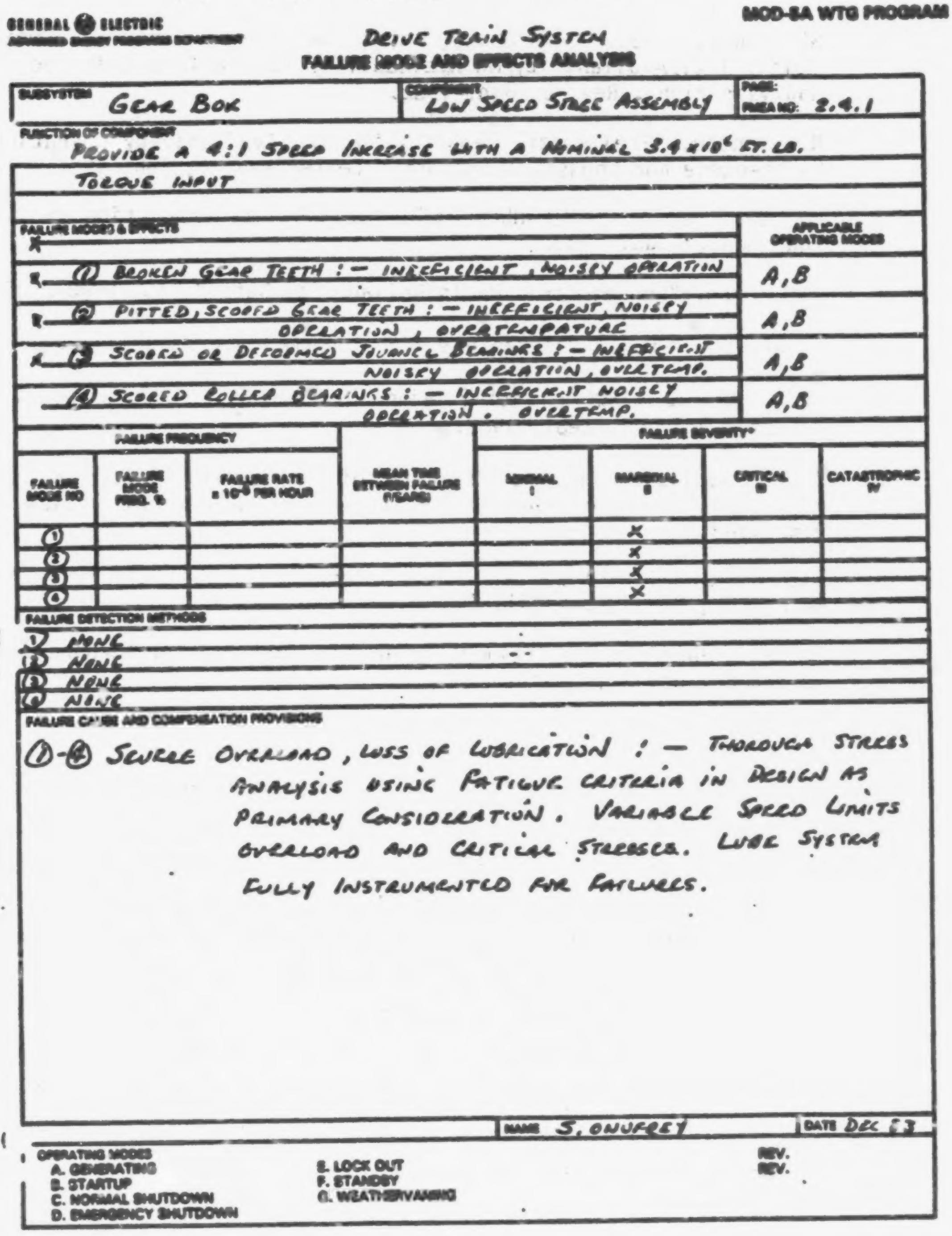

GENERAL ELECTRIC
ADVANCED ENERGY PROGRAMS DEPARTMENT

MOD-5A WTG PROGRAM

DRIVE TRAIN SYSTEM
FAILURE MODE AND EFFECTS ANALYSIS

SUBSYSTEM GEAR BOX	COMPONENT LOW SPEED STAGE ASSEMBLY	PAGE: FMEA NO: 2.4.1

FUNCTION OF COMPONENT
PROVIDE A 4:1 SPEED INCREASE WITH A NOMINAL 3.4 x 10⁶ FT. LB.
TORQUE INPUT

FAILURE MODES & EFFECTS	APPLICABLE OPERATING MODES
X	
x ① BROKEN GEAR TEETH: — INEFFICIENT, NOISEY OPERATION	A,B
x ② PITTED, SCORED GEAR TEETH: — INEFFICIENT, NOISEY OPERATION, OVERTEMPATURE	A,B
x ③ SCORED OR DEFORMED JOURNAL BEARINGS: — INEFFICIENT NOISEY OPERATION, OVERTEMP.	A,B
④ SCORED ROLLER BEARINGS: — INEFFICIENT NOISEY OPERATION. OVERTEMP.	A,B

FAILURE FREQUENCY				FAILURE SEVERITY*			
FAILURE MODE NO	FAILURE MODE FREQ. %	FAILURE RATE x 10⁻⁶ PER HOUR	MEAN TIME BETWEEN FAILURE (YEARS)	MINOR I	MARGINAL II	CRITICAL III	CATASTROPHIC IV
①					X		
②					X		
③					X		
④					X		

FAILURE DETECTION METHODS
① NONE
② NONE
③ NONE
④ NONE

FAILURE CAUSE AND COMPENSATION PROVISIONS
①-④ SEVERE OVERLOAD, LOSS OF LUBRICATION: — THOROUGH STRESS ANALYSIS USING FATIGUE CRITERIA IN DESIGN AS PRIMARY CONSIDERATION. VARIABLE SPEED LIMITS OVERLOAD AND CRITICAL STRESSES. LUBE SYSTEM FULLY INSTRUMENTED FOR FAILURES.

NAME S. ONUFREY
DATE DEC 83

OPERATING MODES
A. GENERATING
B. STARTUP
C. NORMAL SHUTDOWN
D. EMERGENCY SHUTDOWN
E. LOCK OUT
F. STANDBY
G. WEATHERVANING

REV.
REV.

Figure 13-2 Typical FMEA Sheet #2

13.3.2 APPLICABLE DOCUMENTS AND REFERENCES

The documents applicable to the reliability analysis include:

1. GE Cont. Doc. 47A380020, "MOD-5A wind Turbine Generator: Reliability/Availability/Maintainability and Failure Mode and Effects Analysis Plan," Rev. B, Jan. 1982.
2. R. Lynette, "Preliminary Report - MOD-5A, Availability Operations and Maintenance and Logistics Support," Letter report, Feb. 1981.
3. Military Handbook, MIL-HDBK-217D, "Reliability Prediction of Electric Equipment," Jan. 1982.
4. R.G. Arno, "Non-electric Parts Reliability Data," RADC-NPRD-2, 1981.
5. NASA-WTDB, "MOD-OA Discrepancy Reports Summary," unpublished, 1982.
6. NASA CR No. 168007, "MOD-2 Wind Turbine System Development Final Report," Vol. 11, Sept. 1982.
7. NASA-Unpublished Report, "Failure of Low Speed Shafts in DOE/NASA MOD-2 Wind Turbine Generators - Report of Government Review Team," Jan. 1983.
8. W.E. Klein, "MOD-OA WTG Mean Time Between Failures (MTBF)," NASA-WEPO, PIR 192, April, 1982.
9. NASA-TM, Unpublished Preliminary Draft, "MOD-2 Wind Turbine As-built Government Review," April 1983.

13.3.3 RELIABILITY

Reliability is defined as the probability that a component or subsystem will perform its required function under specific conditions for a specific period of time. The mean time between failures (MTBF) and the failure rate, equal to 1/MTBF, quantify the reliability of a component. A failure is defined as the termination of the ability of a component to perform its required functions. However, as it applies to the MOD-5A, a component failure may or may not result in a system's failure to perform its function. Therefore, component failures and failure rates are classed as critical or non-critical. Critical failures interrupt system operation for the time required to repair or replace a component. Non-critical failures only affect scheduled or unscheduled maintenance requirements at the system level.

The reliability analysis for the MOD-5A assumes that failure rates for standard mechanical, electrical, and electronic components can be predicted, based on established data taken in similar environments. For structural components, the reliability is based on existing wind turbine experience and FMEA's. The reliability of a structural component, by design, is higher than that of the more predictable mechanical, electrical, electronic components. However, experience shows that more conservative structural designs are required to cope with the dynamic load complexities of large wind turbines and their effects on mechanical and electrical components.

In the process of changing the design to reduce the risk of a structural failure, the complexity of the design can increase and produce a net decrease in the system's reliability. This decrease in reliability can be shifted from critical to non-critical components.

The ultimate design goals are to optimize reliability and maintainability for maximum availability. In many cases, the cost of increased reliability can be justified. For the same reasons, the economic trade-offs between reliability and maintainability almost always favor maintainability. Decreasing the mean time required to repair or replace a component, and preventative maintenance can easily offset any decreases in reliability incurred by increasing the design's complexity. This concept of increasing maintainability to increase reliability is used throughout this RAM study.

The reliability scenario accomplishes the following objectives:

1. Minimizes the risk of critical structural failures.
2. Increases reliability and decreases forced outages by shifting failures from critical to non-critical components or by using redundancy.
3. Offsets increased failure rates caused by complexity by designing for maintainability, diagnostics, interchangeability, and maximum operational availability.
4. Provides a Safety and Control System that can discriminate between critical and non-critical failures, can provide unattended failsafe operation, and can detect and communicate maintenance requirements.

The control system includes a warning for benign failures or for failures in redundant subsystems and components, to avoid unnecessary shutdowns or forced outages. It provides redundant instrumentation to prevent false shutdowns.

The increased complexity of the control system and power generation system is offset by the increased reliability of other subsystems and by reductions in the MMTR. The failsafe electronics are independent of the control system and enhance protection by using redundant instrumentation to protect the system from control system or sensor malfunctions.

13.3.4 RELIABILITY ANALYSIS METHODOLOGY

The reliability analysis defines the parts of a design and the operational or environmental stresses from design specifications. Reliability data, in the form of representative average failure rates were obtained from refs. 13.3-2 through 13.3-6, and summed, with appropriate duty cycle modifications.

Once the parts were defined in terms of failure rates, the number of failures per year and the mean time between failures (MTBF) were determined. These numbers are the portion of the system's reliability that can be predicted. Parts of the design for which reliability cannot be predicted, for example, structural members, are defined "not to fail" or to have a negligible number of failures per year. In structural fatigue applications, a failure rate or MTBF can be derived from design criteria for the number of cycles to failure, but design specifications for MOD-5A make these numbers very small compared with the predictable failure rates of repairable or replaceable components.

A failure rate is associated with a MTTR. Although reliability is a desirable design characteristic at all levels, it depends on the maintainability and availability requirements at the total system level, using MTTR data.

Applicable failure rate data is given in section 13.3.8 and is summarized in Table 13-2.

13.3.5 RELIABILITY - WIND TURBINE EXPERIENCE

The statistical predictability of a wind turbine's reliability is based on the analysis and summation of failure rate data for similar standard, commercially available components. The wind turbine system is composed of such a large number of these components that the predictability of a system's reliability depends on the number of components, rather than the accuracy of the numbers.

The way in which the components are assembled and the operational stress environment and response of the components also affects the reliability of the system. Experience is an important ingredient that helps to define the design's reliability.

Experience with utility-scale wind turbine generator systems that deliver more than 1 MW, and that are designed for automatic failsafe operation, cannot provide statistically meaningful data. The four MOD-OA machines, rated at 200 kW, accumulated over 36,000 hours of operating time and had 179 documented component failures between 1977 and 1982. The reliability data accumulated in this period was beginning to provide some meaningful data at the system level. Interpretation of the MOD-OA discrepancy reports provide some valuable insight into the common causes of system failures and the relative failure rates of major subsystems, as shown in Table 13-3.

Although a significant amount of information on system failures is available on MOD-2, in references 13.3-6, 7, 9, the three machines at Goldendale, Washington accumulated only 3700 hours of operating time, which is not enough operating time to provide any meaningful statistical data. The failure mechanisms observed on MOD-2 significantly influenced the design of the MOD-5A wind turbine, especially with regard to the increased size and power rating. The design of the MOD-5A focused on the potential failures observed and the concerns expressed in ref. 13.3-9 as a result of the MOD-2's operational history.

The MOD-OA failures listed in Table 13-3 can be averaged to indicate trends. The first two machines, at Clayton and Block Island, accumulated more operational time and failures than the units at Culebra and Kahuku. The last two machines were up-graded in design, and were also in a more favorable, steady-state operational environment.

Table 13-2 MOD-5A Reliability Data for Model 304.2

Major Contributors	AVG. NO FAILURES PER YR.	AVG. NO. OF MAINTENANCE EVENTS PER YR.	MTBF (HOURS)
1. **Rotor System**			
- Aileron Subsystem (bearings/seals)	.60	.60	14,600
- Blade subsystems	.07	.13	130,750
-Yoke subsystems (rotor bearings)	.12	.34	25,028
(teeter mechanism)	.34	.40	26,550
	1.13	1.47	7,750
2. **Drivetrain System**			
- Low speed shaft subsystem	.05	.05	175,200
- Gearbox subsystem	.16	.20	54,750
- High speed shaft subsystem	.32	.39	27,375
- Lube (LSM) subsystem	.13	.72	67,385
	.66	1.37	13,270
3. **Hydraulic Systems**			
- Yoke subsystem (pitch/teeter)	1.37	2.93	6,394
- PSC subsystem (outboard)	.68	3.38	12.882
- Yaw drive/brake subsystem	.80	2.35	10,950
	2.85	8.66	3,075
4. **Elect. Power Generation System**			
- Generator subsystem	1.17	1.17	7,487
- Power gen. protection subsystem (shutdowns)	.47	.47	18,638
- Misc. HV equip. subsystem	.76	1.05	11,526
- Aux. power subsystem	.34	.34	25,765
	2.74	3.03	3,200
5. **Control and Instrumentation System**			
- Control equip. subsystem	2.55	3.00	3,435
- Oper. instr. subsystem	.57	.68	15,368
- Oper. control sensor subsystems (warnings)	-	8.99	-
(shutdowns)	1.15	1.92	7,617
- Failsafe elect. sensor subsystem	.17	.41	51,529
	4.44	15.00	1,970
Nacelle, Tower, and Site Systems			
- Yaw subsystem (bearing/yaw drive mech.)	.09	.09	97,300
- Lighting, environ, control subsystems	-	7.00	-
- Access, safety, & security subsystems	.05	.90	175,200
	.14	7.99	62,570
TOTAL	11.96	37.51	732

Table 13-3
MOD-OA Discrepancy Reports (1977-1982)
Common Causes of Failures Resulting in Shutdowns

36,750 Operating hours - 4 Machines
152 Automatic Shutdowns - 27 Manual Shutdowns
(136 Failures, 6 Safety, 10 False Failures)

SUBSYSTEM/COMPONENT SOURCE	FAILURES		COMMENTS
Control System	81		Over 50% of auto shutdowns
- Sensors		23	10 Wind sensor failures Others: Thermocouples Ice detectors Pressure switches RPM-MAG pickup Meters
- Calibration Errors		3	
- Switches		12	
- Relays		6	
- Power Supplies		17	
- Controller/Circuit Boards		15	Mostly circuit boards
- Wiring		5	Shorts - open circuits
Hydraulic Systems	34		
- Pumps/Motors		3	
- Seals		13	Leaks-lo press. shutdowns
- Hydraulic Couplings		13	Deubling coupling-seals
- Valves, Cylinders		5	
Lube System	11		
- Seals		10	Lo pressure-leaks
- Filter		1	Corrosion
Electrical System	15		
- Generator		3	Stator problems
- Relays, Switchgear		5	One breaker failure, relays
- Sliprings		6	Broken wires-brushes
- Wiring		1	Shorts/open circuits
Drivetrain System	23		
- Couplings		6	Mostly broken bolts
- Brake		11	6 mechanical/5 hydraulic
- LS Shaft/Bearings		2	
- HS Shaft/Bearings		4	
Rotor System	9		
- Rivets/Bolts		4	Mostly inspection Observations with Maintenance repairs
- Cracks		2	
- Shins, etc.		3	
Yaw System	6		
- Mechanical		5	
- Brakes		1	
	179		

(Note: The causes of many failures are subject to interpretation)

The average amount of operating time per MOD-0A machine is about 9200 hours, or 1.31 years, at an 80% duty cycle. Therefore, the data in Table 13-3 can be annualized as follows:

	AVERAGE FAILURES PER MACHINE	AVERAGE NUMBER OF FAILURES PER YEAR	% OF TOTAL FAILURES/ YEAR	MTBF (HOURS)
Rotor System	2.25	1.7	5%	5150
Drivetrain System	8.50	6.5	19%	1350
Yaw System	1.50	1.1	3%	7960
Hydraulic System	8.50	6.5	19%	1350
Control System	20.25	15.4	45%	570
Power Gen. System	3.75	2.9	9%	3020
MOD-0A Sys. Totals	44.75	34.1	100%	257

This data indicates high failure rates associated with the control system, the hydraulic system, and the drivetrain system. Comparing the failure rates of these systems using MOD-0A data and MOD-5A predictions, indicates similar trends, but shows significant improvements on the MOD-5A. The control system failure rate is reduced by a factor of 3.50, the hydraulic system by a factor greater than 2, and the drivetrain system by a factor greater than 9. The projected failure rate is reduced by a factor of 2.8.

Analysis of the MOD-1, MOD-2, MOD-5A, and MOD-5B designs indicate 10-12 failures per year. This value results in a system MTBF of 700 to 900 hours, which is similar to other mature utility power generating systems. Reference 3-8 discusses MOD-0A MTBF data and shows that with the upgraded design and ideal operating conditions, the MTBF approached above 600 hours for the last two machines. This experience confirms the predictability of component and system reliability and establishes the credibility of the MOD-5A analysis.

13.3.6 RELIABILITY - AFFECT OF DESIGN CHANGES

In addition to the effect of design changes on the reliability of structural components, which may not be apparent in the failure rate criteria, the failure rates and MTBF of the applicable components change with the degree of complexity and with changes in operational stress factors. The reliability burden can be shifted between subsystems. For example, the main rotor bearing now interfaces with the yoke subsystem and the nacelle subsystem instead of being a part of the drivetrain subsystem. Component reliabilities change with the revised operational stress factors of new designs. A brief description of the effect of specific design changes on the failure rates of the systems and subsystems, as shown in Table 13-2, follows.

Yoke: The important considerations in the revision of the yoke design were to provide structural redundancy, minimum risk, and benign failure modes. The new yoke subsystem design accommodated the non-rotating rotor support shaft. The support and torque transmitting functions are separated. The teeter system and main rotor bearing assembly are included in the yoke subsystem as major rotor support functional interfaces in the operational stress environment. The teeter bearing and seals can be replaced without removing the rotor.

Ailerons: The use of ailerons removed the aerodynamic control mechanism from the primary blade load path and distributed it as a secondary load along the 60% blade spar. As a result, the weight of each blade was reduced 35,000 lbs. The complexity of multiple aileron structures and actuators was balanced by the increase of the structural reliability of the blade subsystems, without compromising performance.

Blades: The blade span was not changed during the program, but the planform and thickness changed significantly. As the load was refined, the mass and stiffness were major sources of change. Results of development testing of the laminated wood structures and a greater knowledge of wood failure phenomena drove the design into a classical weight and stiffness iteration mode. The blade chord length and thickness were changed to achieve acceptable strength and stiffness characteristics, increase confidence in the design, and reduce the risk of failure. The change from the partial span control to aileron control greatly enhanced the blade's structural reliability. Deterioration caused by transient stress and fatigue were the major mechanisms of failure. The reliability of the blade subsystem was effectively unchanged, but the changes should increase confidence in the design and reduce the risk of failure.

Drivetrain: The predictable failure rates and risk of unpredictable failures, were lowered by the changes to the design of the drivetrain system. The non-rotating rotor support shaft eliminated bending fatigue as a cause of failures in the main rotor bearing, the low speed shaft and the gearbox and intermediate couplings. The variable speed generator reduced or eliminated design loads and drivetrain requirements for components such as the gearbox, couplings, brake, and slip clutch. The removal of mechanical components associated with drivetrain stiffness, damping control and the speed changer enhance the reliability of the drivetrain. Failure rate criteria for the drivetrain also include the requirements for the reliability of the lubrication service module. Minor design changes, including failure detection and diagnostics in the lubrication system sensors, were incorporated.

Hydraulics: Failure rates in hydraulic systems were almost always attributed to leakage in valves, hoses, fittings, pumps, actuators, and accumulators. Therefore, components with high reliability are the first consideration. Parallel redundancy of check valves is used in the MOD-5A hydraulic systems to isolate potential failures. Fail-safe operation is used in all hydraulic systems to provide automatic shutdown despite the loss of a critical hydraulic function. Redundancy also protects against the loss of a critical function and can minimize unnecessary shutdowns caused by an indicated or actual pressure or fluid loss.

Yaw Mechanism: Design changes did not affect the reliability of the yaw mechanism. The applicable failure rate criteria is related to the yaw bearing and seals and the yaw drive and brake assembly.

Tower and Nacelle: Predictable subsystem failures were shifted to non-critical maintenance items, to increase reliability at the system level. The reliability of the tower structure was increased by using an experienced vendor to provide a structural design with a minimum risk. The failure rate criteria pertains primarily to lighting and environmental control systems, and to access safety, and security systems. Most of these failures are considered to be non-critical.

Power Generation Equipment: The effect of a variable speed generator on reliability and maintainability was significant. The unpredictable effects of operational flexibility and load alleviation enhanced the reliability of all components and subsystems. The change makes the drivetrain subsystem much simpler, with no speed changer requirements, no complex gearbox mounting requirements, and fewer constraints on the gearbox, brake system, slip clutch, couplings and shafts. Although failure rates are much higher for the more complex power generation subsystem, the failures affect the average annual outage time very little.

Controls: The changes to the control system increased the complexity of the system, but provided in the additional redundancy and diagnostics required for and greater maintainability. The variable speed subsystem had a relatively complex control for the solid-state power conversion equipment. Reliability data for this subsystem was included in the power generation equipment data.

Changes to this system during the final design phase provided additional protection, reduced the risk of unpredictable failures, and increased the system's maintainability and availability.

13.3.7 RESULTS AND CONCLUSIONS

The results of the reliability analysis for the MOD-5A model 304.2 indicate that the system has three disadvantages: unusually large rotating components, an extremely severe dynamic environment, and the requirement for autonomous, failsafe operation. Reliability projections are based on operational experience with similar subsystems, but without much meaningful data. The MOD-5A's reliability characteristics are consistent with its predecessors, even with the major modifications that minimize risk and optimize performance. In conclusion, current estimates of reliability, including failure rates, and MTBF's, for large, utility-class wind turbines are probably realistic for operationally mature systems, but need to be verified by field experience.

These predictions must have credibility for the utilities to accept the MOD-5A. Improvements to the design do not necessarily increase reliability or availability; they may improve predictability and the design's credibility instead. This analysis evaluated the effect of recent design changes on these predictions, and the the results indicate that reliability improved. More importantly, the analysis established credibility in the MOD-5A design.

13.3.8 RELIABILITY -- MOD-5A PREDICTABLE FAILURE RATE DATA

SYSTEM/SUBSYSTEM/COMPONENT	FPY	MAINTENANCE EVENTS	MTTR (HRS)
1.0 Rotor System			
- Aileron Subsystems			
1. Aileron Journal Radial Bearings	0.10	0.10	24
2. Bearing Seals and Lubrication	0.20	0.20	24
One Blade Total	0.30	0.30	24
Two Blade Total	0.60	0.60	24
- Yoke Subsystem			
1. Main rotor Bearing (3-bearing set)	.035	.035	360
2. Main rotor Bearing Seals	.09	.30	24
3. Teeter Bearings (4-elastomeric)	-	.01	24
4. Teeter Bearing Seals (weather guard)	-	.05	16
5. Teeter Snubbers, Brakes, Stops	.34	.34	16
TOTAL	.46	.74	43.4
- Blade Subsystem	.067	.133	254
SYSTEM TOTAL	1.13	1.47	45.5
2.0 Drivetrain System			
- Low Speed Shaft Subsystem			
1. One pair of 1/2 couplings	.05	.05	12
- Gearbox Subsystem	.16	.20	120
- High Speed Shaft Subsystem			
1. Couplings (2)	.10	.10	12
2. Rotor Holding Brake	.07	.14	8
3. Slip Clutch	.15	.15	12
- Lube (LSM) Subsystem			
1. AC Pump and Motor (Redundant)	-	.35	8
2. Shaft Pump (Redundant)	-	.10	8
3. Accumulator	.10	.10	16
4. Reservoir Sump (tank)	.01	.01	8
5. Reservoir Heater	.01	.01	4
6. Heat Exchanger	-	.02	8
7. Filter	.01	.13	4
SYSTEM TOTAL	.66	1.36	38.1

3.0 Hydraulic Systems

- Yoke Subsystems (Pitch/Teeter Systems)

1. Reservoir Tank	.05	.12	8
2. Hydraulic Tubing and Fittings	.02	.60	8
3. Motor and Pump	.24	.35	12
4. Accumulators (4)	.40	.40	16
5. Check Valves (2)	.06	.06	8
6. Back Pressure Valves (2)	.10	.30	8
7. Feather Valve A	.15	.45	8
8. Feather Valve B	.15	.45	8
9. Teeter System Control Valves	.20	.20	16
SUBSYSTEM TOTAL	1.37	2.93	12.2

- Aileron (Outboard) Subsystem

1. Pitch Actuator	.08	.24	36
2. Feather Latch Actuator	.08	.24	36
3. Hydraulic Tubing/Fittings/Filter	.04	.60	8
4. Servo Valve	.07	.29	24
5. Servo Block Valve	.03	.16	8
6. Bypass Valve	.04	.16	8
1. SUBSYSTEM TOTAL	.34	1.69	24.5
2. SUBSYSTEM TOTAL	.68	3.38	24.5

- Yaw Drive/Brake Subsystem

1. Reservoir	.05	.12	8
2. Hydraulic Tubing/Fittings/Filter	.01	.60	8
3. Motor/Pump	.24	.35	12
4. Accumulators (2)	.20	.20	16
5. Motive Brake Control Valve	.05	.20	16
6. Holding Brake Control Valve	.05	.20	16
7. Actuators (8) (Redundant)	.16	.24	12
8. Check Valves (2)	.04	.04	8
SUBSYSTEM TOTAL	.80	2.35	13.0
SYSTEM TOTAL	2.85	8.66	15.4

4.0 Electrical Power Generation System

- Generator Subsystem (Variable Speed Package)

1. Generator	.100	.100	48
2. Cycloconverter/Control Electronics	.915	.915	8
3. Switch Gear	.101	.101	22
4. Isolation/Step-up Transformers	.030	.030	20
5. Accessories	.014	.014	18
	1.170	1.170	14.0

4.0 Electrical Power Generation System (cont'd)

- Power Gen. Protection Subsystem (Breaker Trip)

1. Main Breaker	.02	.02	4
2. Generator Ground Fault Relay	.03	.03	6
3. Generator Over-current Relay	.03	.03	6
4. Generator Phase Control Unbalance	.03	.03	6
5. High Differential Current Relay	.03	.03	6
6. Transformer Secondary Fault Relay	.03	.03	6
7. Over-voltage Relay	.01	.01	6
8. Over/Under Frequency Relay	.03	.03	6
9. Improper Phase Sequence Relay	.05	.05	6
10. Step-up Transformer Over-temp.	.03	.03	8
11. Step-up Transformer Liquid Level	.15	.15	8
12. Total Over-current Relay	.03	.03	6
	.47	.47	6.7

- Miscellaneous High Voltage Equipment Subsystem

1. Cables and Conduit	.01	.30	4
2. Lightning Arrestor/Ground	.05	.05	8
3. Yaw/Rotor Sliprings	.70	.70	8

- Auxilary Power Subsystem

1. Batteries	.10	.10	3
2. Battery Charger	.02	.02	6
3. Auxilary Power Transformers (2)	.02	.02	6
4. 120V Inverter	.20	.20	8
	.34	.34	6.3
SYSTEM TOTALS	2.74	3.03	10.0

5.0 Controls and Instrumentation System

- Control Equip. Subsystem

1. Controller (Nacelle)	2.25	2.25	4
2. Intercom/Remote TV	-	.25	-
3. Telephone Modem/Keyboard/Display	-	.20	-
4. Connectors, Relays, Wiring	.30	.30	8
	2.55	3.00	4.5

- Operational Instrumentation Sensor Subsystem

1. Wind Sensors (2)	.40	.40	8
2. Rotor/Generator Speed Sensors (2)	.14	.14	8
3. Ambient Temp. Sensor	-	.04	-
4. Generator Voltage Meter	-	.01	-
5. Generator Power Meter (kW)	.03	.03	3
6. Generator Power Meter (kVAR)	-	.03	-
7. Kilowatt-hour Meter (kW-HRS.)	-	.03	-
	.57	.57	7.7

5.0 Controls and Instrumentation System (cont'd)

- Operational Control Sensor Subsystem

1. Tip Position Sensors (2)	.13	.13	16
2. Vibration Sensors	.10	.10	8
3. Intrusion Sensors (mag. relay)	.05	.05	1
4. Blade Strain "High" Gage (2)	.02	.24	16
5. Pitch Hydraulic Accumulator "Lo" Pressure (2)	.12	.30	8
6. Teeter Brake Status Fault Sensors	.13	.13	6
7. Pitch Hydraulic "High" Filter P (3)	.18	.45	8
8. Speed Sensor-High Limit Switch	.14	.14	8
9. Lube Lo Supply Pressure (Redundant)	-	-	-
10. Lube Temperature Sensors (Redundant)	-	-	-
11. Generator Lube Pressure "Lo"	.06	.15	8
12. Generator Bearing/Winding Temperature "HI"	.02	.06	8
13. Yaw Error 10° Sensor (5 minute)	.03	.03	8
14. Yaw Holding Brake Status Sensor	.13	.13	8
15. Lockout Relays	.01	.01	4
	1.15	1.91	8.5

- Failsafe Electronics Subsystem

1. G-switches - Emergency Feather (2)	.12	.36	8
2. Emergency Stop Switches	.01	.01	4
3. Controller Output Fault Check	.01	.01	6
4. Generator Over-current Relay	.03	.03	6
	.17	.41	7.3

6.0 Tower, Nacelle, and Site Systems

- Yaw Subsystem

1. Yaw Bearing/Weather Shield	.01	.01	1500
2. Yaw Drive/Brake Mechanism	.08	.08	12
	.09	.09	177

- Lighting, Environ. Control Subsystems

1. A/C Warning Lights/Strobes	-	6.00	1
2. Nacelle Environ. Control Sys.	-	.05	4
3. GCE Environ. Control System	-	.15	4
4. Nacelle/GCE/Tower Lighting and Outlets	-	.80	1
	-	7.00	-

- Access, Safety, and Security Subsystems

1. Lift, Hoist Assemblies	-	.50	4
2. Fire Protection Subsystem	-	.15	4
3. Doors, Ladders, Railings	-	.05	4
4. Intrusion Alarm Subsystem	.05	.20	4
	.05	.90	4.0
SYSTEM TOTALS	.14	7.99	115

13.4 AVAILABILITY ANALYSIS

13.4.1 INTRODUCTION

The availability analysis takes into account forced and planned maintenance outages. One goal of a wind turbine design is to minimize outages. The RAM projections vary with sites and users. The availability predictions are based on the reliability and maintainability of an operationally mature system. The evaluation of availability for any site is a measure of the wind turbine's performance and will be monitored by the utilities and compared with the availability of other power generation systems.

13.4.2 APPLICABLE DOCUMENTS AND REFERENCES

The documents applicable to the availability analysis include the following:

1. GE Cont. Doc. 47A380020, "MOD-5A Wind Turbine Generator: Reliability/Availability/Maintainability and Failure Mode and Effects Analysis Plan," Rev. B, Jan. 1982.
2. EEI Pub. No. 77-64, "Report on Equipment Availability for the Period, 1967-1976," Dec. 1977 (Alos NERC 1970-1979 "Report on Equipment Availability").
3. EPRI P-2410SR, "Technical Assessment Guide," May 1982.
4. E.S. IDA, "Redundancy Used in Fail-Safe Alarm Design," pg. 89 Control Engineering, Feb. 1983.

13.4.3 AVAILABILITY

Availability is defined as the probability that a system is capable of operating, but not necessarily in service. For components or major subsystems the availability is based on the mean time between failures (MTBF) and the mean time to repair (MTTR), as follows:

$$A = \frac{MTBF}{MTBF + MTTR} = \frac{\text{Time Available}}{\text{Total Time}}$$

The MTBF of components is based on operating time. It is converted to calender time by dividing by the component's duty cycle in percent of total time, generally 8760 hours per year. The duty cycle accounts for the availability of the equipment, including time out of service because of low winds. The MTTR is based on the maintainability of the equipment and on the operation and maintenance of the wind turbine generator system.

The availability of systems is based on calender time, on predictable forced outages, and on operating and maintenance. It is calculated annually according to the following equations:

$$A = \frac{AH}{PH} = \frac{PH - AAO - SM}{PH}, \text{ where}$$

PH = Period hours/yr. (8760 hours)

AH = Number of hours/yr. that the system is available for operation, whether or not it is actually in service.

AAO = Average annual outage time caused by a critical component failure

(Note: Unscheduled maintenance is not part of the AAO, and is considered to be part of O&M).

SM = Scheduled or planned maintenance.

Operating and maintenance will significantly affect the prediction of the wind turbine's availability, represented by the average annual outage and the scheduled maintenance time.

13.4.4 OPERATION AND MAINTENANCE (O&M)

The O&M plan that supported the availability analysis includes the following assumptions:

1. Available time is equal to the period time, less the average annual outage time and the time for any scheduled maintenance that cannot be performed during low wind. This equation assumes that in a commercial application, the utility will use wind turbine power when it is available and that the wind turbine will not be removed from service for any reason when there is statistical probability of winds above the cut-in speed.
2. The AAO and SM time will vary with O&M and the operational maturity of the wind turbine. AAO and SM will approach the projected goals as the design matures.
3. The AAO and SM predictions are from the optimum O&M schedule for maximum operational availability, including the appropriate use of low wind time for scheduled and unscheduled maintenance.
4. Any non-commercial activities, such as research and development testing, is allocated to the available time.
5. The MTTR depends on the skills of the maintenance workers, operational attendance and dispatch schedules, availability and delivery time for spare parts and maintenance equipment, and most importantly, adequate redundancy, and diagnostics for critical and non-critical failures.

6. The MTTR and the AAO do not include cases in which maintenance is repeated because the initial diagnosis or maintenance was inadequate. These calculations assume that the maintenance staff is experienced.

The design specification for the wind turbine's operational availability calls for a "minimum availability of 91% when the wind is between cut-in and cut-out speeds." The scenarios also assume that the specification applies to the most limited O&M for a single unit with fully automatic, unattended, fail-safe operation. A cluster with a dedicated maintenance staff would have lower repair times.

13.4.5 AVAILABILITY ANALYSIS AND METHODOLOGY

As discussed in Sections 13.4.3 and 13.4.4, availability is depends on the inherent reliability of the design and on the operating and maintenance plan. The MTTR of components is used to estimate outage times. All equipment down-time, including repairs, inspections, overhauls, and general maintenance, is summed to determine the system's availability.

Generally, a design change increases reliability, but decreased reliability can be acceptable if the objective is to reduce the probability of critical failures, to reduce repair times, to increase maintainability or to increase operational availability. These objectives have been satisfied in a few cases by eliminating unnecessary shutdowns, and by using a more complex, sophisticated safety and control system. In most cases, parallel redundancy in the instrumentation and fail-safe control devices increase reliability, especially with regard to loosing protection and avoiding unnecessary shutdowns, as described in reference 13.4-4. However, the trade-offs between reliability, safety, and maintainability, and availability were addressed in each application.

Avoiding unnecessary shutdowns and discriminating between critical and non-critical failures increased the reliability of the equipment and decreased the AAO time of the system. The design must include a failure detection and warning system. The safety and control system is the largest contributor to wind turbine failures and maintenance outages, as indicated in References 13.3-1, -5, and -6. The hydraulic system is also a large contributor. Changes were made to provide both systems with redundant features, to improve operational availability and safety. The availability of subsystems, systems, and the entire wind turbine are shown in Table 13-4.

Table 13-4
MOD-5A Availability Analysis for Model 304.2

	FPY	MTBF (HRS.)	MTTR (HRS.)	AAO (HRS.)	AVAIL
1.0 Rotor System					
- Aileron Subsystem (bearings and seals)	.60	14,600	24	14.4	.9984
- Blade Subsystem	.07	130,000	254	17.0	.9980
- Yoke Subsystem (Rotor bear./seal)	.12	73,000	123	14.8	.9983
(Teeter Mechanism)	.34	25,760	16	5.4	.9994
	1.13	6,490	46	51.6	.9950
2.0 Drivetrain System					
- Low Speed Shaft Subsystem	.05	175,000	12	0.6	.999
- Gearbox Subsystem	.16	54,750	120	19.2	.9978
- High Speed Shaft Subsystem	.32	27,400	11	3.5	.9996
- Lube (LSM) Subsystem	.13	67,400	13	1.7	.9998
	.66	13,270	38	25.0	.9971
3.0 Hydraulic Systems					
- Yaw Subsystem	1.37	6,394	12	16.4	.9981
- Aileron Subsystem	.68	12,880	24	16.3	.9981
- Yaw Drive/Brake Subsystem	.80	10,950	13	10.4	.9988
	2.85	3,074	15	43.1	.9951
4.0 Elect. Power Gen. System					
- Generator Subsystem	1.17	7,490	14	16.4	.9981
- Power Gen. Protection Subsys.	.47	18,640	7	3.3	.9996
- Misc. HV Equip. Subsystem	.76	11,530	8	6.1	.9993
- Aux. Power Subsystem	.34	25,765	6	2.0	.9998
	2.74	3,197	10	27.8	.9968
5.0 Control and Instrumentation System					
- Control Equip. Subsystem	2.55	3,435	4	10.2.	.9988
- Oper. Instr. Subsystem	.57	15,370	8	4.6	.9995
- Oper. Control Sensor Subsystem	1.15	7,615	8	9.2	.9990
- Failsafe Elect. Sensor Subsys.	.17	51,530	8	1.4	.9998
	4.44	1,973	6	25.4	.9971
6.0 Nacelle, Tower and Site Systems					
- Yaw Subsys. (Bearing and Yaw Drive Mechanism)	.09	97,333	177	15.9	.9982
- Lighting, Environ. Control Subsys	-	-	1	-	-
- Access, Safety & Security Subsys	.05	175,200	4	0.2	.9999
	.14	62,570	115	16.1	.9982
TOTALS	11.96	732	16	189.0	.9784

The wind turbine's availability is predicted to evaluate the effects of outages on revenue and maintenance, as reflected in Table 13-4. The availability parameters for specific sites should not include values for scheduled or unscheduled maintenance. The system's availability depends on the O&M plan for scheduled and unscheduled maintenance, on the environment, and on the operational maturity of the wind turbine. The O&M plan and operational maturity of the wind turbine do affect the cost of energy and maintenance costs. The base annual average outage times shown in Table 13-4 are calculated for a cluster, an experienced dedicated crew, and a mature design.

13.4.6 RESULTS AND CONCLUSIONS

The statistical results of the availability analysis are shown in Table 13-4. They show average failure rates and maintainability of the equipment over a 30-year life under normal operating conditions. They assume maturity in design, in operation and maintenance procedures, and in power systems management. These goals will not be achieved by the first wind turbine, or within the first five years of commercial operation of any unit or cluster.

The results indicate that there is a considerable margin to account for periods of excessive outage during the early years of operation. Minimum availability goals for the initial wind turbine are shown in Table 13-5, showing the expected increase in availability and projected maintenance requirements for the first five years of operation. These goals are a more realistic interpretation of availability, applied to operation and maintenance requirements, and of how the design specifications can be met during the life of the machine.

Fully attended operation, in two or three shifts, is required in the first year. Attendance decreases to unattended operation after five years. The resulting O&M plan is shown in the table.

Table 13-5

INCREASE IN AVAILABILITY FOR THE INITIAL UNIT
MINIMUM AVAILABILITY TARGETS - 60% TO 90% OVER 5 YEARS

Year	Allocated Availability	Total Down Time	Allocated Scheduled Maintenance Hours	Allocated Unscheduled Outage Hours	Allocated Average Crew Size	Allocated Labor	
						Labor Hours	Labor Years
1st	0.60	3,504	1000	2504	3.0	10,512	5.05
2nd	0.70	2628	600	2028	2.5	6,570	3.16
3rd	0.80	1752	400	1352	2.0	3,504	1.68
4th	0.85	1314	200	1114	1.5	1,970	.95
5th	0.90	876	90	786	1.175	1,030	.50

The average crew skills are assumed to be: 10% supervision, 50% electrical and electronic, and 40% mechanical and hydraulic.

To establish the credibility of the availability analysis, the wind turbine's availability was compared with actual availabilities of other power generating systems, as shown in Table 13-6. The data from Ref. 13.4-2 is a broad sample of power generating equipment in the United States and Canada. Because both machines depend on a renewable and varying energy source, low head hydro was selected by the user review board for these comparisons. As a conservative comparison, the availability projections for the initial, single machine in its fifth year of operation was used. Compared with the availability analysis in Table 13-4, the obvious differences, other than the allocated availability, are the annual unscheduled outage time and the average MTTR. Both of these parameters change significantly from single to cluster applications, because a cluster has a dedicated maintenance crew and spare parts. The availability comparisons, especially with systems other than hydro, support these projections. The wind turbine's average annual outage time is much higher than that of a hydro system because of the number of forced outages. It is more comparable to single unit fossil, diesel, and gas turbine equipment. Also, it should be noted in these comparisons that the MOD-5A is designed to detect faults quickly, so that faults may be repaired easily.

13.5 MAINTAINABILITY ANALYSIS

13.5.1 INTRODUCTION

Maintainability, in contrast to maintenance, is characteristic of the design. Equipment maintainability is measured by the time required to repair or replace an item. It generally establishes the maintenance requirements. Maintainability depends on the reliability of the equipment in terms of the projected failure rates and the estimated unscheduled maintenance events per year. The design determines the planned or scheduled maintenance requirements by designing procedures that will prevent failures, such as inspections, and overhead. The MTTR for scheduled and unscheduled events and the average crew size both depend on the design and describe the maintainability of components and subsystems.

13.5.2 APPLICABLE DOCUMENTS AND REFERENCES

1. R. Lynette, "Preliminary Report - MOD-5A, Availability, Operation and Maintenance and Logistics Support," Letter Report, Feb. 1981.
2. "MOD-2 Wind Turbine System Development Final Report," NASA Cr. No. 168006, Sept. 1982.

Table 13-6

SYSTEM RELIABILITY AND AVAILABILITY COMPARISONS

(UTILITY OPERATIONAL EXPERIENCE - REF: NERC 1970-79)

ANNUAL AVERAGES FOR MATURE DESIGNS

Item	MOD-5A 1st Unit Single Unit	Low Head Hydro*	Diesel	Fossil	Gas Turbine
MTBF	768	8946	1044	897	872
Availability %	90.0	94.4	94.5	82.6	86.0
Total Downtime	876	493	481	1504	1187
Unscheduled Hours/Year	786	193	447	781	907
Scheduled	90	300	34	723	282
Forced Outages/Year	11.41	0.98	8.33	9.67	9.75
MTTR - Hours	69	197	54	81	93

* Low-Head Hydro was selected by the user review board because, like the wind turbine, it is non-combustible, and variable, for availability projections only.

13.5.3 MAINTAINABILITY

During the design and development of the wind turbine, reliability was emphasized because the actual reliability cannot be better than the designed reliability. The operational reliability is typically lower than the design's capability and will depend on the maintainability of the equipment and on the operation and maintenance plan.

Maintainability in design must assure that the equipment can be repaired and replaced conveniently. The maintenance process will involve the O&M plan for maintenance personnel, skill mix and training, spare parts and delivery times, and contracted maintenance services and equipment. Design features minimize the time required to diagnose equipment failures and generally reduce operation and maintenance costs. The major detractors from reliability were identified. Design efforts concentrated on these component, especially in the control and instrumentation, and hydraulic and lubrication subsystems. These subsystems cause over 70% of all projected failures. The forced outage times are decreased by avoiding critical failures and by reducing the MTTR.

The forced outage time and MTTR depend on maintenance labor, spare parts inventory, and maintenance equipment resources and services. The assumptions for optimizing the O&M plan for minimum cost and lost revenue are:

1. Forced outages and the average annual outage time only reflect time lost as a result of critical equipment failures that produce an automatic shutdown. The time required to restore the equipment to operational status, including failure diagnostics and delivery time for spare parts is included.

2. Outages for unscheduled maintenance are not considered forced outages. They are non-critical failures with diagnostics and warnings that alert monitors to the maintenance requirements. Unscheduled maintenance can be performed during periods of low wind, forced outages, and scheduled or planned outages.

3. Operational availability and maintainability in the early years will be lower than those predicted for an operationally mature unit. Availability will increase with experience. This analysis assumes operational maturity.

4. Scheduled or planned maintenance outages are assumed for a mature design. In the early years outages will be more frequent and more extensive.

5. Scheduled maintenance can be performed during wind outages, to minimize the effect of failures on availability and revenue. Decisions not to shutdown for planned maintenance while wind is available are as important as the allocation of maintenance workers and spare parts.

6. Maintenance labor requirements meet only the basic, equipment-related maintenance and service specifications. They do not include time waiting for parts or services or the travel time of maintenance workers. They do not take into account time-sharing in clusters, but do take into account time-sharing the utility's maintenance workers.

7. The recommended spare parts are assumed to be available. The inventory is based on predicted component failure rates. Site-specific O&M plans and cost-effectiveness studies on the inventory and availability of spare parts vary for each application.

The maintainability scenario in this analysis attempts to separate the basic equipment requirements from the site-specific requirements, which may not be known until the wind turbine is operating. The numbers are for an mature wind turbine system and mature components. Inadequate maintenance, and installation and design deficiencies, should be expected initially, but they are not projected in this analysis. These deficiencies will be eliminated as the wind turbine matures.

13.5.4 MAINTAINABILITY ANALYSIS AND METHODOLOGY

The projected maintainability and maintenance requirements are shown in Tables 13-7, 8 and 9. The maintenance requirements for critical forced outages and for unscheduled maintenance events are derived from the reliability and availability sections of this analysis. They use the failure rates and MTTR's of individual components, subsystems, and systems of the wind turbine, as described in Section 13.3.8. Maintenance labor is allocated to each subsystem in efficient O&M plans, a proper combination of skills, and characteristic equipment designs. The average maintenance requirements are then summed to calculate the wind turbine system's requirements for unscheduled maintenance events in Table 13-7 and for scheduled maintenance events in Table 13-8.

Unscheduled and scheduled maintenance are performed concurrently, not sequentially. Therefore, the effect of maintainability on outage time and operational availability of the equipment depends on the O&M plans. With effective use of wind outages, the effect of downtime on operational

Table 13-7
MOD-5A Maintainability and Unscheduled Maintenance Events

	UNSCHLD MAINT. EVENTS PER YR.	MTTR (HRS)	AVERAGE APPLIED MTTR (HOURS)	AVG. CREW SIZE	TOTAL MAINT. LABOR-HOURS	AVERAGE MAINT. LABOR-HRS PER YEAR
1.0 Rotor System						
- Aileron Subsystem Bearings	.60	24	16	3	48	28.8
- Blade Subsystem	.13	254	48	3	144	18.7
- Yoke Subsystem						
(Rotor Bearing/Seals	.34	123	24	3	72	24.5
(Teeter Mechanism)	.40	16	12	2	24	9.6
	1.47					81.6
2.0 Drivetrain System						
- Low Speed Shaft Subsys	.05	12	8	2	16	0.8
- Gearbox Subsystem	.20	120	16	2	32	6.4
- High Speed Shaft Subsys.	.39	11	8	2	16	6.2
- Lube (LSM) Subsystem	.72	13	8	1	8	5.8
	1.36					19.2
3.0 Hydraulic Systems						
- Yoke Subsystem (Pitch/Teeter)	2.93	12	8	1	8	23.4
- Aileron Subsys. (Outboard)	3.38	24	20	1	8	67.6
- Yaw Drive/Brake Subsys.	2.35	13	8	1	8	18.8
	8.66					109.8
4.0 Elect. Power Generation System						
- Generator Subsystem	1.77	14	8	2	16	18.7
- Power Gen. Prot. Subsys.	.47	7	4	1	4	1.9
- Misc. HV Equip Subsys.	1.05	8	4	2	8	8.4
- Aux. Power Subsystem	.34	6	2	1	2	.7
	3.03					29.7
5.0 Control and Instrumentation System						
- Control Equip. Subsystem	3.00	8	2	1	2	6.0
- Oper. Instr. Subsystem	.68	8	2	1	2	1.4
- Oper Control Sensor Subsystem (2)	10.91	8	2	1	2	21.8
- Failsafe Electronic Sensor Suosystem	.41	8	2	1	2	.8
	15.0	—	—	–	—	30.0
6.0 Nacelle, Tower, and Site Systems						
- Yaw Subsys. (Bearing/Yaw Drive Mech.)	.09	177	20	3	60	5.4
- Lighting, Environ. Control Subsys.	7.00	4	2	1	4	14.0
- Access, Safety, and Security Subsys.	.90	4	2	2	4	3.6
	7.9	—	—	–	—	23.0
TOTAL	37.51					293.3

Table 13-8
MOD-5A Maintainability and Scheduled Maintenance

	FREQUENCY PER YR.		ALLOTTED AVG. TIME PER EVENT	ALLOCATED	
	INSPECT	SERVICE		AVG. CREW SIZE	LABOR-HRS PER YEAR
1.0 Rotor System					
- Aileron Subsystem (Bearing/Seals)	2	1	8	2	32
- Blade Subsystem	2	0	8	2	32
- Yoke Subsystem (Rotor Bear/Seals)	6	1	4	1	24
(Teeter Mechanism)	6	0	4	1	24
					112
2.0 Drivetrain System					
- Low Speed Shaft Subsystem	2	0	2	1	4
- Gearbox Subsystem	2	0	4	2	16
- High Speed Shaft Subsystem	6	2	4	2	48
- Lube (LSM) Subsystem	6	6	4	1	24
					92
3.0 Hydraulic Subsystem					
- Yoke Subsystem (Pitch/Teeter)	6	6	4	1	24
- Aileron Subsystem (Outboard)	2	1	8	1	16
- Yaw Drive/Brake Subsystem	6	6	4	1	24
					92
4.0 Elect. Power Generation System					
- Generator Subsystem	6	2	8	1	48
- Power Gen. Protection Subsys.	6	2	4	1	24
- Misc. HV Equip Subsystem	2	0	2	1	4
- Aux. Power Subsystem	6	2	2	1	12
					88
5.0 Control and Instrumentation System					
- Control Equip. Subsystem	0	1	4	1	4
- Oper. Instr. Subsystem	6	2	4	1	24
- Oper. Control Sensor Subsystem	6	2	8	1	48
- Failsafe Electronics Subsystem	6	2	2	1	12
					88
6.0 Nacelle, Tower, and Site Systems					
- Yaw Subsystem (Bearing/Yaw Drive Mech.)	2	1	4	2	16
- Lighting, Environmental, Control Subsystems	6	6	2	1	12
- Access, Safety, and Security Subsystems	6	2	4	1	24
					52
TOTAL	6	6	13.8	6*	496

*See Table 13-9

Table 13-9

MOD-5A Baseline Maintenance and Labor Requirements
Totals for an Operationally Mature System

A. Predicted Avg. Annual Outage Hrs. (AAO)	189 hours/yr.
Available Maintenance Hrs. at 1 Shift/Day	63 hours/yr.
at 1.5 Shifts/Day	95 hours/yr.
at 2.0 Shifts/Day	126 hours/yr.
Avg. Number of Failures (shutdowns) per yr:	11.96
MTTR per Failure:	16 hours (total downtime)
Available Maintenance Time/Failure (1 shift):	63/11.96 = 5.3 hrs.
Average Crew Required for Forced Outages:	2
Average Labor-hrs/year for Forced Outages:	127.8 Labor-hrs/yr.
B. Predicted Number of Unscheduled Maintenance Events:	37.51 Events/yr.
Average Maintenance Labor-hrs/year:	293.3 Labor-hrs/yr.
Average Maintenance Labor-hrs/Event:	7.8 Labor-hrs/Event
C. Predicted System Scheduled Maintenance Events:	6 per yr.
Average Total Scheduled Hrs/Yr.:	82.7 hrs/yr.
Average Scheduled Maintenance Crew:	6
1 Electronics Technician:	88 Labor-hrs/yr
1 Controls Tech.:	88 Labor-hrs/yr
1 Hydraulics and Lube Technician:	88 Labor-hrs/yr
3 Mechanical/Electromech. Technicians:	232 Labor-hrs/yr
Average Total Scheduled Labor-hrs:	496 Labor-hrs/yr

Note: Painting is not included. Painting would be contracted.

D. Total Estimated Annual Average Labor Requirements	
Forced Outages:	127.8 Labor-hrs/yr
Unscheduled Maintenance	293.3 Labor-hrs/yr
Scheduled Maintenance	496.0 Labor-hrs/yr
TOTAL	917.1 Labor-hrs/yr
E. Total Estimated Average Downtime Per Year	
Forced Outage Time:	189 Hrs/Yr.
Scheduled Outage Time:	83 Hrs/Yr.
Wind Outage Time:	1752 Hrs/Yr.
Using NASA's Design Wind Characteristics	

availability and revenue can be minimized. The relationships between the baseline maintenance requirements, available maintenance time, and allocation of maintenance workers is shown in Table 13-9.

The analysis assumes that in most cases external maintenance aloft will not be allowed when wind speeds are above the cut-in speed, since it is unsafe, even for critical failures that initiate automatic shutdowns or prevent start-ups. However the forced outage time and MTTR should reflect the fact that the machine is not available for maintenance or for operation during these periods. For this reason, the projected MTTR for certain subsystems will be low for environments that have long periods of wind above the cut-in speed. Therefore, the maintenance plan shown in Table 13-9 may vary, especially the number of shifts available for maintenance, the MTTR per failure, and the estimated maintenance labor hours per year. The analysis assumes that there will be enough periods of low wind to perform scheduled and unscheduled maintenance. The number of shifts available for maintenance is site-specific, but one shift per day appears to be adequate for most situations.

13.5.5 RESULTS AND CONCLUSIONS

The maintenance requirements for an operationally mature system are summarized in Table 13-9. The requirements are consistent with realistic O&M plans. Provisions for maintainability were part of the design process and were an important consideration in some of the final design changes. For example, the rotor support was redesigned to allow the teeter mechanism components and main rotor bearing seals to be replaced without removing the rotor. The MTTR for the electrical power generation system was reduced when the variable speed generator and electronic power conditioning and regulation were introduced. Improved failure diagnostics and discrimination used in the control system reduce the MTTR of many other components and subsystems and reduce the number of unnecessary shutdowns.

The maintenance requirements derived from this analysis will change as the O&M plan changes. A more conservative approach is generally required for specific applications, as shown in the maintenance plan presented in section 13.6.

13.6 MAINTENANCE PLAN

13.6.1 INTRODUCTION

To ensure safe and efficient operation, maintenance must be carried out according to schedule, beginning with the initial operations. The intervals for some procedures will be extended as operating experience is accumulated. Both scheduled and unscheduled maintenance requirements will probably be greater in the early years. Detailed operation and maintenance manuals will be prepared for each installation and updated periodically to accommodate changes in the design and O&M plan. The maintenance plan is presented in two parts: the labor and service requirements that include both the initial periods of operation and operational maturity, and general operating and preventative maintenance requirements.

The maintenance plan is the basic ingredient of the O&M manuals. It evolves directly from the reliability, availability, and maintainability analysis. The requirements are generally for a single-unit installation, but some availability and maintainability goals are based on clusters. The recommended spare parts list is an extensive inventory, more characteristic of early single-unit installations . Site-specific O&M plans and cost effectiveness studies determine the appropriate inventory for each application.

13.6.2 LABOR AND SERVICE REQUIREMENTS

The maintenance requirements for an operationally mature system were presented in section 13.5 and are summarized in Table 13-10. The results of the maintainability analysis indicate that the size and combination of skills of qualified, trained personnel for a single-unit installation should include three mechanical, one electrical, one controls, and one hydraulics and lubricating technician, a total of six technicians. These technicians will be scheduled as follows: two technicians on one shift 38 times a year for unscheduled maintenance, and all 6 technicians on one shift 6 times a year for scheduled maintenance. A total annual labor requirement is estimated at 917 labor-hours, which indicates that time-sharing maintenance workers with other wind turbines or power generation systems is feasible. Other maintenance support services, such as painting and heavy duty cranes, are required periodically and are contracted.

Table 13-10

LABOR AND SERVICE REQUIREMENTS

Year	Allocated Unscheduled Time	Allocated Scheduled Time	Total Hours	Average Crew Size	Average Allocated Labor	
					Labor-Hours	Labor-Years
1st	2,504	1,000	3,504	3.0(1)	10,512	5.05
2nd	2,028	600	2,628	2.5(1)	6,570	3.16
3rd	1,352	400	1,752	2.0(1)	3,504	1.68
4th	1,114	200	1,314	1.5(1)	1,970	.95
5th	786	90	876	1.175(1)	1,030	.50
nth	189	90	279	2(2)	917	.46

(1) Attended operation (2-3 shifts)

(2) Unattended operation (1 shift)

Maintenance requirements during the first five years of operation of the prototype were projected in section 13.5 to account for increased availability with increased operational experience. Outage time is expected to decrease as operational experience increases during the first five years. Although the anticipated crew size and combination of skills are comparable to an operationally mature, unattended system, the applied labor-hours and downtime will be much greater.

Anticipated support services and maintenance equipment that may be required periodically include: painting, cranes, cherry picker, generator service, elevator service, mechanical repair service, and systems engineering analysis. Although many of the services may be routine, such as elevator inspection and service, painting or oil analysis, others will be contracted when required, and cannot be factored into a maintenance plan unless the utility's maintenance organization can perform the task.

13.6.3 GENERAL OPERATING AND PREVENTATIVE MAINTENANCE

General operating and preventative maintenance consists of monthly, quarterly, semi-annual, and annual inspection, lubrication, and replacement of expendable parts. During the early years of operation, it also includes a thorough inspection with functional checks following the first 100, 500, 1,000, 2,500, and 5,000 hours of operation. In the inspections, loose parts, loose bolts or nuts, frayed wires and cables, fluid leaks, peculiar noises, arcing, paint chips, and rust will be examined.

A routine quarterly inspection is required for key structural components, including the yoke and teeter mechanism, spindle and rotor support structures, and the upper and lower yaw structures and bearing assembly. The primary structural load paths that are subjected to fatigue loading are identified for periodic inspection for fatigue cracks, and paint chips, which may identify potential structural failures. Routine quarterly inspections will include a check of the lubricating and hydraulic system, and instrumentation and control system sensors.

The primary planned maintenance schedule is based on a 6-month interval and is outlined in Table 13-11. Detailed maintenance procedures, recommended by vendors, will be given in the operations and maintenance manuals and may not be identified in this maintenance plan. All of the major maintenance items are included in Tables 13-11, 12, and 13. The maintenance schedule for the aileron and teeter hydraulic control system is shown in Table 13-12 and indicates an annual maintenance interval after the first year. A typical yaw system maintenance schedule is shown in Table 13-13, which also shows the variation in the frequency of service for various components. The consumables are listed in Table 13-14.

13.6.4 RECOMMENDED SPARE PARTS

The spare parts list recommended for local inventory is in Table 13-15. The list is an extensive inventory for the early MOD-5A applications. Until adequate experience is achieved, this inventory should be maintained to ensure the wind turbine's maintainability. The site-specific O&M plan and cost effectiveness studies determined the inventory of spare parts for other applications. Renewal parts can be stocked in various regions when there are enough wind turbines to make this plan feasible. Stock will include large items, such as gearboxes and generators.

Table 13-11

Planned Maintenance Schedule (6 Month Intervals)

Subsystem	6 Month Maintenance
Blade	Inspect structure/aileron hinges/bearings Inspect trailing edge assembly Inspect tip assembly/ballast adjust Test relief valves, hydraulic functions
Drivetrain	Lubricate low speed shaft couplings Analyze lubrication oil Clean lube oil filter Clean magnetic plug Lubricate bearings of lube pump Motor Inspect lube heater operation Lubricate high speed shaft couplings Inspect torque plate
Steel Structure (Yoke, Spindle, Bedplate, Yaw Structure, and Tower)	Inspect for fatigue cracks and damage
Lift Device (Elevator)	Inspect wire ropes Check overload switch adjustment Inspect automatic brake Check lube oil level Change lube oil (seasonal) Lubricate wire rope
Rotor Yoke/Spindle	Grease blade retention bearings Grease main bearing seals Tighten blade retention nuts Tighten main bearing nuts Inspect magnetic plug Inspect teeter mechanism Inspect low speed brake assembly
Nacelle/Electrical	Test fire protection system Inspect ventilation systems Check generator insulation resist Check generator lube/cooling Inspect slipring assemblies Inspect relays/breaker/XFMRS

Table 13-12

AILERON CONTROL & TEETER CONTROL HYDRAULIC SYSTEMS MAINTENANCE SCHEDULE

Maintenance Function	Service Frequency
1. Change Hydraulic Fluid (Dexron II)	First change after six months of operation, every 2 years thereafter.
2. Change Filter Element	First change after six months of operation, once every year thereafter.
3. Check Accumulator Pre-Charge	First check after 3 months of operation, once every year thereafter.
4. Check for Leakage	At least once every 3 months.*
5. Check Fluid Level	At least once every 3 months.*
6. Check for indication of Actuator Rod Wear	At least once every 3 months.*
7. Check - Charge and Slew Pump Discharge Pressures	At least once every 3 months.*

Table 13-13

YAW SYSTEM MAINTENANCE SCHEDULE

Maintenance	Service Frequency
1) Change Hydraulic Fluid (Dexron II)	First change after six months, every 2 years thereafter.
2) Change Filter Element	First change after six months of operation. Every year thereafter.
3) Check Accumulator Pre-Charge	First check after 3 months of operation, once every year thereafter.
4) Checking for Leakage	Once every 3 months.*
5) Check Fluid Level	Once every 3 months.*
6) Checking Pump Operation	Once every 3 months.*
7) Check Drive Motor Gearbox Oil Level (Add as needed - SAE 90)	Once every 3 months.*
8) Lubricate Yaw Bearing (Bel-Ray 126EP2)	Once every 2 years.
9) Lubricate Pinion Retainer Bearings (Bel-Ray 126EP2)	Once every 2 years.
10) Lubricate Pinion Retainer Gear Teeth (TENAC M)	Once every year.
11) Change Yaw Motor Gearbox Oil (Mobile HP90 or equal)	Once every four years.
12) Lubricate Pinion-to-Motor Coupling	Once every year.

* First year of operation only; yearly thereafter.

Table 13-14

SUMMARY OF REQUIRED CONSUMABLES

Designation	Source	Quantity Required to Fill
Aeroshell 22	Shell Oil Co. Distributors	Blade retention bearings and main bearing seals: 25 lb.
Turbo 32	Shell Oil Co. Distributors	Generator bearings: 1 gal.
Mobil SHC 629	Mobil Oil Corp. Distributors	Gearbox: 110 gal.
Dexron II	Convoy Oil Corp. 1410 N. Front St. Phila., Pa. and other distributors	Yaw Hydraulics: 40 gal. Yoke Hydraulics: 150 gal.
Molylube 126 EP2	Bel-Ray Co., Inc. P.O. Box 526 Farmingdale, N.J. 17727	Yaw Bearing: 300 lb. LS Couplings: 22 lb. HS Couplings: 4 lb. Yaw Coupling: 10 lb.
Mobil Cylinder Oil 600 W Mobile Lube HD85W140	Mobil Oil Corp. Distributors	Lift Device: 2 qt.
Silicone Wire Rope Aerosol Spray (Sprayon No. 201 or equivalent)	Local Suppliers	Lift Device Wire Rope: 16 oz.
Tenac M	E. F. Houghton & Co. 303 West Lehigh Ave. Phila., Pa. 19133	Yaw drive gear and pinion: 10 lb.
MOBIL HP90 (SAW 90 gear oil)	Mobil Oil Corp. Distributors	Yaw motors: 4 gal.

Table 13-15 Recommended Spare Parts List

Subsystem: Control Sensors

ITEM	DESCRIPTION	QTY
1	Ice Detector	1
2	Blade Temp.	2
3	Tip Position	2
4	Pressure Switches	8
5	Temp. Switches	2
6	Limit Switches	4
7	Flow Switches	2
8	Accelerometer	1
9	Magnetic Switches	2
10	Position Switches	2
11	RVDT	1
12	LVT	1
13	PT's	3
14	CT's	3
15	Generator KW	1
16	Gen. Overcurrent	2
26	Accelerometer	2
27	"G" Switch	1
28	Relays	2
29	Wind Speed & Direction	1

Subsystem: Rotor S/S

ITEM	DESCRIPTION	QTY
1	PSC Actuator	1
2	PSC Bearings	1 set
3	PSC Servo Block Valve	1
4	PSC Bypass Valve	1
5	PSC Relief Valve	1
6	PSC Act. Seals	2
7	PSC Act Rod End Bearings	2
8	PSC Flex Hoses	Misc.
9	PSC Fittings	Misc.
10	PSC Piping	Misc.
11	PSC filters	2
12	PSC Pump Seals	Misc.
13	Gaskets	Misc.
14	Hydraulic Fluid (55 gal. drums)	3
15	Teeter Brake Assy	4
16	Teeter Brake Fittings and Pads	4 sets
17	PSC Servo Valve	1
18	PSC Feather Valve	1
19	Valves	Misc.
20	Gauges, Press	Misc.

Table 13-15 Recommended Spare Parts List (Cont'd)

Subsystem: Instrument and Control S/S

ITEM	DESCRIPTION	QTY
1	Controller Cards	4
2	Controller I/O Modules	4
3	Controller Power Supply	1
4	Mux Cards	6
5	Mux Pwr Supply	2
6	Failsafe Card	1
7	Failsafe Card Components	Misc.
8	Interface Cards	3
9	Misc. Pwr Supplies	4
10	Panel Meters	10
11	Blower Motor	1

Subsystem: Drivetrain

ITEM	DESCRIPTION	QTY
1	Gearbox Oil (55 gal. drums)	11
2	Grease	AR
3	Rotor Brake Pads	1
4	Slip Clutch Friction Plate	1
5	Rotor S/R Brushes	1 set
6	Rotor Brake Assy.	1

Subsystem: Yaw S/S

ITEM	DESCRIPTION	QTY
1	Yaw Brake Assembly	4
2	Yaw Brake Fittings and Pads	4 sets
3	Hydraulic Fluid (55 gal drums)	2
4	Yaw Actuator	2
5	Yaw Act. Seals (sets)	3
6	Yaw S/R Brushes	1 set

Table 13-15 Recommended Spare Parts List (Cont'd)

Subsystem: Power Gen. S/S

ITEM	DESCRIPTION	QTY
1	Generator Fluid (55 gal. drums)	1
2	Circuit Breakers	10
3	Contractors	4
4	Relays	10

Subsystem: Tower S/S

ITEM	DESCRIPTION	QTY
1	Elevator Cables	1000 ft.
2	Elevator Guides	6
3	Elev. Drive Motor	1
4	Brake Disc	1
5	Interlock Switch	1
6	Contactor	1
7	Motor Starter	1
8	Limit Switches	1

Subsystem: Miscellaneous

ITEM	DESCRIPTION	QTY
1	Oil-Dri Absorbent (50# bags)	50
2	Dessicant	1
3	Freon (55 gal. drum)	2
4	Light Bulbs	AR
5	Fuses	AR
6	Nuts, Bolts, Screws Washers	AR
7	Strobe Lights	1

APPENDIX A
C.F. BRAUN & COMPANY - FOUNDATION DESIGN CRITERIA

ORIGINAL PAGE IS
OF POOR QUALITY

C F BRAUN & CO Engineering and Construction Subsidiary of Santa Fe International Corporation

October 7, 1983

Mr E A Leinroth, Jr
Advanced Energy Programs Department
Post Office Box 527
King of Prussia, Pennsylvania 19406

Dear Mr Leinroth

TASK 1 REPORT -
FOUNDATION DESIGN CRITERIA
WIND TURBINE GENERATOR
DESIGN REVIEW
GENERAL ELECTRIC
SUBCONTRACT J19-GE9529
BRAUN PROJECT 6556-N

This letter, with attachments, constitutes our report on Task 1, which is defined in Section 2.1 of your statement of work, SOW No. MOD5A-021, revision A, dated July 20, and the Scope of Work section of our proposal dated June 24.

We have established generic subgrade and foundation design criteria, and identified geotechnical data needs to permit development of further, site-specific design requirements.

In summary, the foundation mat and tower base anchor bolts shall be analyzed and designed to remain stable and undamaged while sustaining the extreme hurricane or normal wind fatigue loads. In order to achieve this, hurricane induced stresses shall be limited by appropriately factored AISC and ACI 318 allowables.

To minimize fatigue effects the "zero-to-peak" amplitude of the foundation rocking motion shall be limited to 10^{-4} radians for 4×10^{8} cycles of the mean average base ring moment of $(24 \pm 24)\ 10^{-3}$ ft-kips. The long term differential settlement shall be limited to a slope of 1:250. Total settlement shall be less than one inch. The geotechnical engineer shall select the allowable soil static and dynamic pressures, embedment depth and other pertinent parameters to meet the above criteria for a mat of about 72 ft in diameter. The geotechnical engineer may also use Miner's rule with the loading histograms shown in PIR 280 in his rheological studies. We have also provided detailed soils investigation requirements for his guidance and use. Please see Braun specification 310-0, attached.

COPY

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The design criteria for the anchor bolt and foundation mat design, shape selection and load documentation are covered in more detail in the attached writing titled MOD-5A WTG Foundation Design Criteria. In summary, here are the key provisions.

Anchor bolts shall be sized to sustain hurricane loads without damage. It appears from preliminary calculations that the cross-sectional area of bolts will be governed by the hurricane. For fatigue loading, the bolt shall be preloaded to eliminate any significant range of stress, and thus insure against bolt failure.

Reinforced concrete design shall be based on ACI-215R, the Portland Cement Association RD059.01B, and ACI-318. The mat shall be sized first for stability and strength under hurricane load in accordance with ACI-318 strength method. The fatigue considerations shall be based on the first two standards, and the working stress method shall be used in checking allowable stresses.

Seismically, the design contractor shall use the UBC method for a zone 3 site. Our conceptual design will be verified using a simplified dynamic analysis with an acceleration response spectrum.

Foundation configuration was investigated by considering four suitable shapes from the viewpoint of constructibility, material quantities and equipment needs. The circular, octagonal, "donut" and square shapes were reviewed. In conclusion, the best shape is the circle, with the octagon a close second.

The principal reasons for selecting the circular shape are simplicity of formwork and smallest potential for reinforcement congestion. Furthermore, the simplest arrangement of rebar can be achieved-all radials are identical in each layer, and pedestal verticals can mesh with the mat rebar in a repetitive pattern.

COPY

For detailed load documentation please refer to Section 7.0 of the Foundation Design Criteria attachment. Our preliminary fatigue calculations are based on document 4, the average mean loading.

Sincerely yours

JAR SG

J A Raulinaitis
Power Engineering

E A Leinroth, Jr - original and two copies of letter, specification 310-0, and criteria attachment

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C F BRAUN & CO

Project 6556-N

Pages 9 Page 1

SPECIFICATION

310-0

Customer General Electric

Location King of Prussia

Date Sept 16, 1983

MOD-5A WIND TURBINE GENERATOR
SOILS AND FOUNDATION
INVESTIGATION

This page is a record of all revisions of the specification. Each time the specification is changed, only the new or revised pages are issued.

For convenience, the nature of the revision is briefly noted under remarks. But these remarks are not a part of the specification. The revised pages are a part of the specification and shall be complied with in their entirety.

Rev	Date	By	Chk	Eng Appr	Client	Pages/Remarks
0	9-16	JAR	DLF			Issued for customer use

1 SCOPE This specification establishes the geotechnical data needs for the generic wind turbine generator foundation design criteria for three types of subgrade - granular, cohesive and hard rock. A subsurface investigation shall be conducted by a qualified consulting soils and foundation engineering firm for any one of the three generic sites. The consultant shall supply all professional services, labor, tools, and equipment to perform the field and laboratory work required for a complete subsurface investigation and report. The investigation and report shall include the determination of the strength and other physical properties of the subgrade at a specific site and shall provide recommendations for the design of foundations.

2 REFERENCES AND SUBMITTALS Paragraph 3 on Project Data lists the drawings and data that will be furnished the Consultant by General Electric, hereafter referred to as GE. The next paragraph, titled Report, describes the report that the Consultant shall prepare and deliver to General Electric. The report is due XX weeks after GE's release to proceed with the work. Send NN copies of the report to GE.

3 PROJECT DATA GE will furnish the consultant the drawings listed below which describe the proposed structure and its loads, load characteristics, and settlement sensitivity. Contact GE at King of Prussia, Pa. for any clarification.

Plot Plan and Locations Drawing Number ______________

Contour Map Drawing Number ______________

Technical Load Data Drawing Number ______________

4 REPORT The report shall describe the site conditions, the nature of the soil deposits, including rock, the general geology of the area, and recent history of excavation, fill, flooding and the like. It shall include the information and recommendations listed under Report Contents, plus such other data and recommendations as are deemed pertinent by the consultant. All recommended allowable soil bearing or load capacity values shall be given for working or service loads. In each instance, the factor of safety used in determining these recommended values shall be stated in the report. All design values and measurements shall be reported in customary English units.

5 SITE EXPLORATION A site exploration shall be made to determine the surface and the subsurface soil conditions and to obtain the data required in this specification. Sufficient borings, test pits or trenches shall be made to give a reliable picture of the subsurface conditions. The depth and number of bore holes required shall be determined from the site conditions, the method of proposed construction, and the data required. GE estimates that 3 borings (2-90 ft deep and 1-120 ft deep) will be required for each location. If bedrock is found at a depth of 40 ft or more, and the overburden can support a mat foundation, the boring may be terminated at the bedrock. If bedrock is found above this depth, the rock shall be cored for a depth of 10 ft. It is the responsibility of the consultant to recommend additional borings or excavations if he thinks they are necessary.

A log of each bore hole shall be made. Undisturbed samples shall be taken at suitable frequencies, from each boring for laboratory testing. The consultant's engineer or technician shall examine and classify the soils in the field. The soil samples shall be further examined and tested in the laboratory.

Where test pits or trenches are required but are not located on the GE drawing, the consultant shall discuss the proposed excavations with the GE Project Engineer before making them. A log of each excavation shall be made similar to those for borings.

After all field work is completed, all bore holes shall be backfilled with compacted soil.

6 BORING LOGS Each log shall include the data listed below.

Name of driller and soils engineer or technician

Date boring was made

Proper identification of the project and boring

Location of boring or excavation based on established plant coordinate system and the orientation of trenches

Ground surface elevation based on established plant datum

Depths at which major changes in the character of the soil take place including the depth of bedrock if encountered

A detailed description of the soil in each major stratum utilizing the Unified Soil Classification System

6 BORING LOGS Continued

Penetration resistance of the sampler and/or an estimate of the consistency of the soil in-situ

Numbers of samples, type of sample (disturbed or undisturbed) and the depths from which they are taken

Any obstructions and difficulties encountered

Depths at which a loss or inflow of water into the bore hole occurs

Depth to free groundwater level

For borings, the diameter and method of casing and advancing the bore hole

The type and diameter of the sampler

Description of the method used to force the sampler into the soil

An indication if drilling mud was used

For Rock:

Rock types

Position of the boring relative to the various rock units or geologic features

Any structural features in the rock such as joints or cavities

The presence of soft soils above or interbedded within the rock strata

Rock compressive strengths

Rock quality description (RQD) which indicates rock quality and fracture frequency.

7 LABORATORY TESTS Laboratory tests shall be made on the soil samples to determine their character and properties as required. In general, the laboratory investigation shall include the tests listed below. It is the responsibility of the consultant to recommend alternative or additional testing if he thinks it is needed. The tests shall follow standard ASTM Methods where applicable.

7 LABORATORY TESTS Continued

Dry density

Moisture content

Shear tests at natural and saturated water-content and with a surcharge equivalent to the existing overburden pressure

For cohesive soils, unconfined or triaxial compression tests to supplement shear tests

Consolidation tests on cohesive soils

Atterberg limits for a representative number of samples of the cohesive soils

Expansion tests

Dynamic tests, see paragraph 8

Test for liquefaction potential, if required - see paragraph 9

8 DYNAMIC PROPERTIES Dynamic data to conduct dynamic response analyses is required. The foundation is a circular mat with an approximate diameter of 72 ft. If the soil conditions are such that, in the consultant's opinion, the structure can be supported on a spread footing, then the following dynamic soil properties shall be determined. If however, the consultant recommends that the structure must be supported on piled foundations, then GE shall be advised of this recommendation before proceeding with the dynamic investigation and analysis.

The following dynamic soil properties, expressed where possible as functions of depth and/or confining pressure, shall be determined. The expected strain levels are about 10^{-4} for cohesive and granular soils, and about 10^{-5} for rock.

Dynamic shear modulus

Mass density

Poisson's ratio

Both estimated viscous and geometric damping of soil expressed as damping ratios

8 DYNAMIC PROPERTIES Continued

Void ratio

One or more of the methods listed herein may be considered for determining the dynamic shear modulus. Static tests shall not be used. The consultant is to review his recommended method with the GE Project Engineer before performing the tests.

Seismic methods. An acceptable seismic method test may be either a down-hole or a cross-hole test. Refraction tests may be used only for preliminary evaluation.

Resonant column tests

Dynamic triaxial tests

The consultant shall state whether or not there will be any degradation of the subgrade due to the long term dynamic loading of the foundation.

9 SEISMIC PROPERTIES The characteristic site period, T_s, as defined by the 1982 edition of the Uniform Building Code, shall be determined. The appropriate range of values for T_s shall be established in accordance with one of the methods outlined in UBC Standard No 23-1.

A determination shall be made whether or not liquefaction of the site during possible seismic shaking could occur, and the report shall state that fact. The consultant shall discuss possible remedies and make recommendations as appropriate.

10 REPORT CONTENTS

Field and Laboratory Work

A brief description of the field work.

A description of each type of laboratory test which was run and what the test was used for.

Results of tests conducted, including explanations and analysis.

General Soils Data

Boring and excavation location maps (plan) - The location maps shall also show where the sections asked for herein were cut.

10 REPORT CONTENTS Continued

Sectional plots of north-south and east-west soil profiles. These profiles should show logs of borings and test pits, soil types, and the approximate water table, and should be complete enough so that structural engineers can evaluate the subsurface soils conditions at the location of the foundation.

Unit weights of soil.

Cohesion and angle of internal friction of the various soils.

Depth and estimated fluctuations of the water table.

Chemical condition of the soils that may affect construction materials.

Relative densities for cohesionless soils.

Void ratios for cohesive soils.

Water content for cohesive soils.

Expansive characteristics of the soils with change in water content.

Foundation Design Data - all generic subgrade types

Allowable net soil bearing pressure versus depth for gravity loads, with long-duration fluctuating wind loads. Note that the foundation design criteria limit the differential long term settlement to a 1:250 slope measured at the anchor ring over the 30 year life, with 4 X 10^8 cycles of wind service load. Total settlement shall be less than 1.0 inch. This load consists of an average gross pressure of about 2.0 ksf (tower weight, foundation and backfill), combined with a peak cyclic pressure at the toe of the mat of about 0.7 ksf, and a peak constant pressure of about 0.7 ksf at the toe of the mat. The above numbers are based on average mean wind load, a rigid foundation, and the conventional Mc/I formula. For the elastic rocking oscillation the maximum half-range rotation is limited to 10^{-4} radians. In the appropriate compaction or consolidation calculations the consultant shall assume that the wind direction remains constant. The allowable bearing pressure shall be specified so as to maintain the differential settlement within the above limits.

10 REPORT CONTENTS Continued

Allowable net soil bearing pressure for temporary loads due to seismic, hurricane, loss-of-rotor accident, and other transient forces. Hurricane forces generally cause the highest transient loading on the foundation. The peak hurricane moment at the base of the mat is about 140 x 10^3 ft-kips.

Approximate shape of static bearing pressure variation curve for the various generic types of subgrade material (cohesive, cohesionless, rock).

Settlement curves for the 72' diameter circular mat

Estimated modulus of subgrade reaction for design of the mat on elastic soil strata.

In addition to the above listed items, provide the following information for foundations on rock.

Minimum depth to competent rock from existing grade

State whether rock anchors are a practical method of resisting high uplift anchor bolt loads

If so, give recommendations for typical practical rock anchor installations (core sizes, minimum free length and bond length, allowable bond stress, creep, provision for retightening, special precautions, etc)

Alternative Foundations Using Piling

Where piles are recommended, the consultant shall provide the following data, where appropriate.

Recommend at least two types of piles commonly used in the area.

Curves showing allowable axial load versus depth both for vertical gravity loads and for uplift for the recommended piles, for long term vibratory loading.

Minimum pile length

Estimated Settlement

Where negative skin friction (downdrag) may be present, comment on design methods to account for these additional loads.

10 FINAL REPORT Continued

Allowable lateral load per pile for a 1/4-inch deflection, assuming piles may rotate in the pile cap, at maximum loads.

Minimum pile spacing for practicality of driving.

Minimum pile spacing to prevent group effects on individual pile capacities.

Provide an equation for evaluating group effects for resisting horizontal and vertical loads, when this minimum spacing cannot be achieved.

Are load tests recommended? If so, outline recommended test procedure.

Recommended approximate hammer energies necessary to drive piles.

Comment on possible pile installation problems, and possible solutions, such as: jetting, vibration, etc.

11 SURVEYING GE will determine the coordinate and elevation datum for the plant and will designate bench marks for survey control. The consultant shall furnish the surveying services necessary for his work.

J A Raulinaitis | Page 1
General Electric | Project 6556-N
King of Prussia | October 7, 1983

MOD-5A WIND TURBINE GENERATOR FOUNDATION DESIGN CRITERIA

1.0 GENERAL REQUIREMENTS This writing defines the criteria to be followed in the generic design of the MOD-5A WTG foundation mat and anchor bolts, and provides a methodology for the design. The fundamental criterion for the design is to prevent damage of the mat and bolts under both limit loads, and fatigue loads which are the normal operating loads.

The limit loads consist of the hurricane and other operational extreme loads, whereas the normal loads are the high-cycle wind-induced vibration loads. The bolts shall be sized to sustain the hurricane loads, and shall also be pre-loaded in order to eliminate any significant range of stress fluctuation.

2.0 APPLICABLE CODES AND STANDARDS These criteria are based on the following documents.

2.1 AISC Specification for the Design, Fabrication and Erection of Structural Steel for Buildings 1978, and its Appendix B, Fatigue.

2.2 Considerations for Design of Concrete Structures subjected to Fatigue Loading, ACI 215R-74, revised 1981.

2.3 Building Code Requirements for Reinforced Concrete, ACI 318-77.

2.4 Final Design Limit Loads for Model 304.1, General Electric, General Electric PIR 283, WTG MOD-5A, 8/83.

2.5 Final Design Fatigue Loads for Model 304.1, General Electric, PIR 280, WTG MOD-5A, 8/83.

2.6 Design of Reinforced Concrete for Fatigue, Portland Cement Association Bulletin RD059.01D, 1978.

3.0 DESIGN LOADS

3.1 LIMIT LOADS These loads are listed in detail in PIR 283, see Section 7.0. The governing load is the infrequently occurring load L-2B hurricane. The overturning moment at the tower base is 121×10^3 ft-kips, combined with a shear of 451 kips, and a vertical load of 1560 kips, all occurring simultaneously.

3.2 FATIGUE LOADS These loads are listed in detail in PIR 280. The design number of load cycles shall be 4×10^8, to be carried without failure of the bolts. The average mean moment at tower base is $(24 \pm 24)\ 10^3$ ft-kips.

5.3 SEISMIC LOAD The WTG foundation mat and anchor bolts shall be designed for zone 3 requirements of the Uniform Building Code, 1982. The occupancy importance factor I shall be 1.0, the horizontal force factor K shall be 2.0.

However, for the conceptual design by Braun, a 100-year recurrence interval response spectrum shall be used. It will be selected by General Electric in consultation with the geotechnical engineer.

3.4 DEAD AND LIVE LOADS The limit and fatigue load tabulations in PIR 280 and PIR 283 include the gravity loads of tower, equipment, stairs and platforms. Ice loading is not included and must be added if required by local codes and conditions.

4.0 ALLOWABLE STRESSES

4.1 REINFORCED CONCRETE

4.1.1 LIMIT LOADS For limit, extreme wind, earthquake, dead and live loads the mat shall be designed in accordance with reference 2.3, ACI 318-77. The strength method of design shall be used.

For bearing of anchor bolt embedded plate on concrete a stress of $3f_c'$ shall be used when triaxial confinement of the concrete is provided.

4.1.2 FATIGUE LOADS After sizing the mat and reinforcement as noted in 4.1.1, the foundation stresses shall be checked in accordance with ACI 215R and PCA RD059.01D. It shall be noted that ACI 215R Section 3.1.1 criterion 2 may conflict with PCA RD059.01D equation 1. Use the more stringent requirement of the two.

4.2 ANCHOR BOLTS Stresses shall be calculated on the basis of tensile stress area. The basic allowable tension shall be $F_t=0.33 F_u$. A one-third increase in allowable stress is permitted for load combinations including hurricane or seismic loads. For the purposes of reference 2.1, Appendix B (AISC), Table B2, stress category D shall apply.

For the sizing of the anchor bolt bearing plate at the embedded end a bearing pressure of $3f_c'$ shall be used.

5.1 REINFORCED CONCRETE

5.1.1 MATERIAL Concrete ultimate strength shall be at least 3000 psi at 28 days. Reinforcement shall be Grade 60 steel conforming to ASTM A615. Bar mats conforming to ASTM A184 may be used, except that clipping is the only method permitted to provide attachment at intersections.

5.1.2 SPLICING Welding is prohibited as a means of splicing of reinforcement bars. Tack welding of any auxiliary materials to the reinforcement is prohibited. Splices shall be made using Cadwelds or other devices not requiring machining of the bars, and are subject to approval by General Electric.

5.1.3 BENDING OF REINFORCEMENT The main vertical bars attaching the tower pedestal to the mat shall be straight, without any sharp bends or hooks. Other bars may be bent, observing the ACI 215R section 3.1.1 stress range reduction. A design using straight bars and long-radius-of-bend circumferential bars is recommended.

5.2 ANCHOR BOLTS

5.2.1 MATERIAL The anchor bolts shall be made of ASTM A 193 grade B7 steel.

5.2.2 LEVEL OF PRELOAD The anchor bolts shall be preloaded to at least 125% of the average mean design load in the bolt. Higher preload may be used to achieve nil or insignificant cycles and magnitude of stress range fluctuation. Unnecessarily high levels of preload are to be avoided. The intent of the design is to essentially eliminate fatigue as a potential cause of failure.

This feature must be coordinated with the detailed design of the tower base so that prying action does not exceed 5% of the design load.

The details of the anchor bolt and tower base shall be such as to permit eventual lift-off using a tensioner for checking pre-load either inside or outside the tower wall. The details shall be such that the nut (or nuts) shall not move due to fatigue loads.

5.2.3 CORROSION ALLOWANCE A corrosion allowance of 1/4 inch on the theoretical diameter of the tensile area shall be provided.

5.2.4 TESTING PROGRAM It is recommended that the owner test the preload after 6 months, again after 5 years of operation on at least 6 bolts per tower. The need for further surveillance shall be based on these first tests.

6.0 FOUNDATION CONFIGURATIONS Four foundation configurations have been investigated: circular, octagonal, "donut", and square. Here is a discussion of their advantages and disadvantages.

6.1 CONSTRUCTIBILITY Constructibility is defined as the relative ease of placing and securing reinforcement, anchor bolts, ducts and other embedments, and of casting the concrete without segregation and voids.

6.1 CONSTRUCTIBILITY Continued

All four foundation configurations require considerable reinforcement, with potential for reinforcement congestion. Careful layout of details is needed in all cases. However, the "donut", shape will be the worst case due to its more elaborate torsional reinforcement, and due to more forming.

The circular configuration appears to be the best shape. The pedestal verticals and anchor bolts mesh with the radial and circumferential bars in the mat in a simple repetitive pattern. All radials are identical for each layer. Congestion of radials at the center can be avoided by introducing a small vertical cylindrical void at the center, and terminating the radials at this imaginary surface. A multi-layer crossing of bars is avoided. To simplify matters, this cylindrical space would be filled with concrete, the "void" being only theoretical.

6.2 CONCRETE QUANTITIES For equal volumes of concrete, which means about equal overturning stability, the square is the best shape for minimizing soil pressure, hence reducing vibrational soil consolidation, and potential differential settlement. The square experiences about a 15% lesser peak soil pressure than the circle or "donut", provided it can be oriented broadside to the prevailing wind. If not, the soil and stability situation is most advantageous for the "donut", circular, octagonal and square shapes, in that order.

6.3 REINFORCEMENT QUANTITIES The most load-efficient arrangement of reinforcement is found in the circular mat, followed by the octagon and donut. The square shape produces unusually high moments in the diagonal direction, necessitating a more complicated bar layout.

6.4 CONSTRUCTION EQUIPMENT NEEDS We see no significant difference in machinery needs for either of the shapes in question. The most straightforward in formwork are the square and the circle, closely followed by the octagon. The more extensive forming will occur in the case of the"donut".

6.5 CONCLUSION We recommend the circular configuration as the most advantageous foundation. The octagon is a very close second, followed by the donut and the square respectively.

7.0 LOAD DOCUMENTATION Seven documents or communications have been made available to Braun describing the WTG loadings.

1. "CBI spread foundation conceptual configuration", attached to June 7 letter to A M DeFusco from E A Leinroth, Jr., marked up with loads.

2. "Proposed foundation", page 5 of CBI proposal request for geotechnical investigation, WTG project, dated August 10, marked up with a somewhat different set of loads. Handed to Braun at September 2 project kick-off meeting.

3. "Support towers and foundation specification for the MOD-5A wind turbine generator", GE spec. 47A380022, August 83.

4. Phone talk with Dr Kugath, August 14, advising Braun to use the average mean tower base moment of $(24 \pm 24)\ 10^3$ ft-kips with 144 ± 97 kips of horizontal shear for foundation considerations.

5. Table of number of cycles with peak shear and overturning moment, datafax from Dr Kugath, dated and received September 15.

6. "Final design fatigue loads for model 304.1", GE PIR 280, August 83, received September 19.

7. "Final design limit loads for model 304.1", GE PIR 283, August 83, received September 19.

We would like to draw your attention to the fact that the loads have been described differently in each of the above documents. Our work is based on document 4.

The histograms in document 6 appear to be the complete load description. However, due to the varying interpretations, we suggest that PIR 280 be clarified by adding graphic definitions of all the terms used. The foundation load table format used by Stearns-Roger (handout 7 of September 2 meeting, pp 790 et seq, SVU Site Subsurface Investigation) would also help to eliminate misinterpretation.

Still in document 6, Table 2, MY, the bottom five values seem to be short an exponent. The table following Table H-108 needs a heading and seems to be missing MX, MY and MZ at tower base.

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APPENDIX B
GE - PRODUCT ASSURANCE PROGRAM PLAN FOR THE MOD-5A WTG PROGRAM

GENERAL ELECTRIC

REV	A	B	C	D

47A380018
CONT ON SHEET 11 SH NO. 1

TITLE

FIRST MADE FOR

47A380018
CONT ON SHEET 11 SH NO 1

REVISIONS

GEN. CHANGES

D | UNDER CONFIG CONTROL 4/6/84

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REV "D"
MARCH 84

PRODUCT ASSURANCE PROGRAM PLAN

FOR THE

MOD-5A WIND TURBINE GENERATOR PROGRAM

PREPARED BY: A. Cheddar DATE: 8-12-81
A. Cheddar, Product Assurance
Engineer
Energy Support Operations

APPROVED BY: E. J. Urbanik DATE: 8-13-81
E. J. Urbanik, Manager
Product Assurance
Energy Support Operations

APPROVED BY: G. Drenker DATE: Aug. 13, 1981
G. Drenker, Manager
MOD-5A WTG Hardware Integration

TOTAL NUMBER OF PAGES 38

W.T.G
530
PRINTS

MADE BY A. CHEDDAR
ISSUED 4/6/84
APPROVALS
A.E.P DIV OR DEPT.
KING OF PRUSSIA LOCATION
47A380018
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REVISION LOG

This log identifies those portions of this document which have been revised since original issue. Revised portions of each page, for the current revision only, are identified by marginal striping.

Revision	Page No.	Paragraph Number(s) Affected	Rev. Date
A	18	Section B. - Removed reference to system Safety and incorporated in separate safety plan. Defined specific responsibility for preparation of FMEA.	8-11-80
B	All	Issued to corract typegraphical error in page numbering.	8-20-80
C	All	Changed document number from PA-MOD-5A-81-001 to 47A380018 Changed paragraph numbering system.	8-06-81
D	All	General Rewrite to remove references PSC, to update organization chart and to correct miscellaneous typegraphical errors.	3-14-84 a.c.

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SECTION 1.0

GENERAL

1.1 APPLICABILITY

This Product Assurance Program Plan describes the Program to be implemented by the General Electric Company, Advanced Energy Programs Department, to fulfill the quality requirements of the NASA-Lewis Research Center MOD-5A Wind Turbine Generator Program. It is designed to provide effective controls which will result in a contractually compliant Wind Turbine Generator for all phases of the contract, from customer specification through design, procurement, manufacture, test and utilization. This plan shall be the controlling document governing the execution of the defined tasks. All revisions, deletions or additions shall be submitted to NASA/LeRC for approval. The Quality System is documented through the use of selected Quality Assurance Procedures (QAP's). These procedures will be implemented with the required revisions, deletions, or additions necessary for meeting the requirements of the MOD-5A Wind Turbine Generator Program.

1.2 MANAGEMENT

Program Management together with Engineering, Product Assurance, Manufacturing and Reliability have the responsibility for interpreting contractual quality and reliability requirements and will determine the applicable policies and detailed procedures under which the MOD-5A Wind Turbine Generator Program will function, subject to NASA/LeRC review.

To implement the quality, reliability and safety requirements, a project team organization is used. The organizational relationships are shown in Figure 1.

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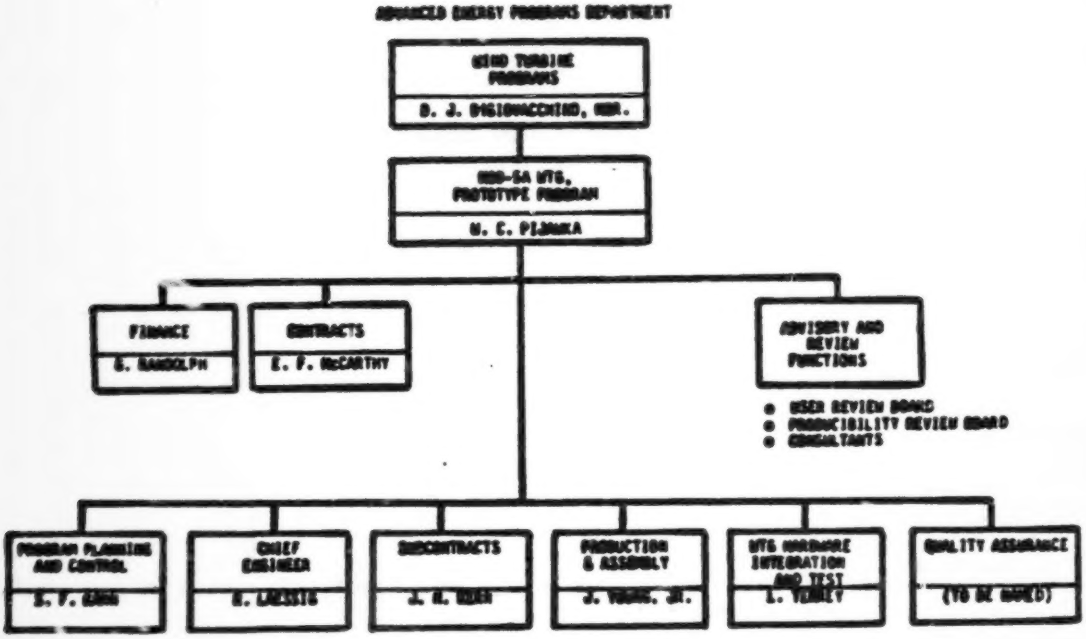
ADVANCED ENERGY PROGRAMS DEPARTMENT
WIND TURBINE PROGRAMS
D. J. DIGIOVACCHINO, MGR.
MOD-5A WTG, PROTOTYPE PROGRAM
W. C. PIJAWKA
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CONTRACTS
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● PRODUCIBILITY REVIEW BOARD
● CONSULTANTS
PROGRAM PLANNING AND CONTROL
CHIEF ENGINEER
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PRODUCTION & ASSEMBLY
J. YOUNG, JR.
WTG HARDWARE INTEGRATION AND TEST
L. YERKEY
QUALITY ASSURANCE
(TO BE NAMED)

Figure 1

The Product Assurance Engineer (PAE) reports technically to the Manager, Hardware Integration, who, in turn, reports to the MOD-5A Program Manager. This provides a line of communication to the Program Manager concerning all aspects of Product Assurance Program implementation.

The Product Assurance Engineer reports administratively to the Product Assurance Manager, who reports to the Energy Support Operations Manager. He has at his disposal the facilities and capabilities of the entire PA organization, dedicated to the product assurance of hardware developed and built at the GE Advanced Energy Programs Department.

The Product Assurance Engineer assigned to the MOD-5A WTG Program is responsible for assuring that contractual, technical and quality requirements are met.

During the design and development phases, he will:

- Review and sign off WTG drawings and specifications for the inclusion of quality requirements.
- Establish supplier quality assurance requirements and generate the quality assurance provisions for product and process specifications.
- Define acceptance requirements with the design engineer.

During the fabrication, inspection and test phases, he will:

- Incorporate quality requirements in purchase orders.
- Review and sign off inspection planning.
- Participate in operations readiness reviews to assure that hardware, test equipment, facilities and personnel are ready for test.

- Review test procedures.
- Assist in the preparation and presentation of hardware data packages for customer acceptance.

Additional quality activities as defined in this Plan are performed by Quality Specialists, Technicians, Planners or Inspection personnel.

1.3 GOVERNMENT REVIEW

The operations and work of GE, its subcontractors and suppliers are subject to audit and review by the government (NASA-LeRC). Upon request, applicable information, documents, records, and other data will be made available for review by NASA-LeRC.

SECTION 2.0

RELIABILITY

2.1 DESIGN REVIEWS

Product Assurance, Reliability, and Safety personnel will maintain cognizance of Design Engineering activities; participate in in-house design reviews; contribute to "Quality Assurance Provisions" for specifications; advise Engineering in areas of inspection, test, reliability, and safety requirements; provide any required inspection and test support; and review drawings and specifications. Engineering is responsible for the technical adequacy of the Design, Test Specifications, and applicable Technical documentation.

2.2 TECHNICAL DOCUMENT REVIEW

Product Assurance Engineering will review those technical documents and changes associated with the MOD-5A WTG hardware, such as specifications, drawings and procedures, to ensure that they contain adequate requirements for determining and controlling the quality of all hardware. The major role undertaken by the Product Assurance Engineer in the review of technical documents will be to assure that the design definition is adequate and clear, that the parameters are measurable, that required tolerances are specified and appropriate, and that any special quality requirements are reflected in the design definition.

Through participation in design reviews and technical document reviews, the Product Assurance Engineer will plan for measuring and test equipment requirements, inspection and test procedures, vendor surveillance, and process control requirements.

2.3 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

An FMEA will be prepared during Preliminary Design to identify initial elements which may cause failures, result in unplanned down time, or adversely affect the operating life of the MOD-5A WTG. The FMEA will be prepared by Design Engineering. Product Assurance, Reliability and Safety representatives will contribute to the FMEA and participate in reviews of the analysis. Similar analyses and reviews on other programs, including the recently completed MOD-1 WTG, have proved beneficial to modifying design concepts, selection of components, establishing planned maintenance intervals and in defining specific inspections and checks to be performed at each planned maintenance interval. The FMEA will be revised and updated during Final Design to incorporate results of design changes and modifications.

SECTION 3.0

PRODUCT ASSURANCE

3.1 QUALITY CATEGORIES

Articles to be used in this program are divided into two (2) categories. The applicable quality assurance requirements for each category are indicated in parentheses following the applicable requirements title.

3.1.1 UNIQUE

Specific unique articles are defined as the blades, ailerons, planetary gearbox and yoke. These specific articles have been designated as unique because of criticality to the success of the program and "state-of-the-art" category in their design and production.

3.1.2 NON-UNIQUE

All other components and equipment designed or procured for the wind turbine are included in this category.

3.2 QUALITY SYSTEMS (Unique and Non-Unique)

The General Electric Company, AEPD, is presently operating an effective system for controlling quality consistent with the requirements of this Product Assurance Plan. The system is integrated with all functions to assure that quality requirements are determined and satisfied throughout all phases of the contract. This system is documented through the use of selected sections of the Quality Assurance Procedures (QAP) Manual. Selected procedures will be implemented to meet the requirements of the MOD-5A WTG Program.

GE Product Assurance prepares and maintains the Quality Assurance Procedures (QAP) Manual. The QAP Manual documents all quality related procedures in detail; it is subject to continuous audit and review.

3.2.1 PRODUCT ASSURANCE ENGINEERING (PAE) MEMOS

It is the responsibility of the MOD-5A WTG Product Assurance Engineer to maintain, interpret and update the Product Assurance Plan as required. To assist in this endeavor, he is authorized to prepare and issue Product Assurance Engineering (PAE) Memos. The PAE Memo, when approved by NASA-LeRC, becomes an integral part of the Product Assurance Plan.

3.2.2 QUALITY ASSURANCE PROCEDURES

Product Assurance has the responsibility for maintenance of the Quality Assurance Procedures Manual and for auditing conformance to the requirements specified therein. In addition, they will be responsible for modifications of GE QAP's as required to effectively satisfy the requirements of the MOD-5A WTG Program.

Product Assurance also has the responsibility for maintaining the configuration verification records and preparation of the equipment logs.

3.2.3 SUPPLIER AND PROCESS CONTROL

Product Assurance has the responsibility for quality surveillance of suppliers, participation in vendor surveys where required and performance of supplier quality audits. In addition, Product Assurance prepares/reviews the process portion of manufacturing instructions and inspection procedures, participates in process readiness reviews and specifies discrepancy corrective action requirements.

3.3 DRAWING AND CHANGE CONTROL (Unique)

The drawing change control program will be in accordance with the standard GE Advanced Energy Programs Department (AEPD) Engineering Section Instructions, Drafting Practices Manual, and Quality Assurance Procedures. These will insure controlled distribution of all unique and non-unique drawings and specifications.

Drawing changes will be incorporated by revision as defined by Alteration Notices (AN's) or Design Change Control (DCC) forms and signed prior to release by Design Engineering, Manufacturing and Quality Assurance.

Upon approval of changes, AN's or DCC's will be issued to define the changes and their effectivity. Copies of all approved AN's and DCC's will be distributed to Product Assurance by the drawing custodian and processed to the responsible PAE and inspection personnel. All inspection and test documentation affected by the changes will be expeditiously revised by Product Assurance Engineering to reflect the new requirements. Drawings and procedures are kept only in one specific area, under the control of Engineering. Obsolete drawings are replaced promptly by Production Control with newly revised signed off copies. Inspections and tests will be performed against the latest MOD-5A WTG released design definition. The configuration status of all assemblies will be continuously monitored by inspection to assure compliance with the latest design definition. This monitoring includes the review of previously accepted hardware to assure that it has not become obsolete by virtue of subsequent design changes.

3.4 PROCUREMENT SOURCE CONTROL (Unique and Non-Unique)

3.4.1 UNIQUE ITEMS

Performance/Design requirements of unique items will be defined by GE-AEPD prepared specifications. Procurement sources will be evaluated and approved prior to issuance of the Purchase Order or Subcontract. Prior to award, suppliers selected must either have a quality record of supplying high quality articles of the type being purchased, or, if no up-to-date quality rating is available, pass a GE survey of the suppliers' facilities and quality control system.

The Quality Assurance Provisions of the Performance/Design specifications will be reviewed by the PAE to assure that the quality requirements are adequately covered. The PAE will also review the procurement documents (Purchase Order, Subcontract, Work Statement, as applicable) to insure that design and test requirements, Quality Assurance provisions, raw material controls, identification, preservation and packaging, cleanliness and contamination criteria, data requirements, etc., are specified.

Detailed inspection and test plans covering inspections and tests to be performed by the supplier will be generated by the supplier and reviewed and approved by the GE-PAE prior to their implementation. These will delineate specific parameters to be inspected or tested, data to be recorded and specific accept/reject criteria for parameters checked. The PAE or his designated representative will verify the quality of hardware supplied through periodic audits of vendor's system and processes, through source inspections of items prior to release for shipment and by witnessing or monitoring acceptance tests at the vendor's facility. Discrepancies, test failures and non-conformances will be documented and will require GE disposition prior to hardware acceptance. Documentation will be included with hardware shipments and will be maintained by GE as part of the Product Assurance Documentation file.

Figure 2 shows a typical flow chart for purchased materials, both unique and non-unique.

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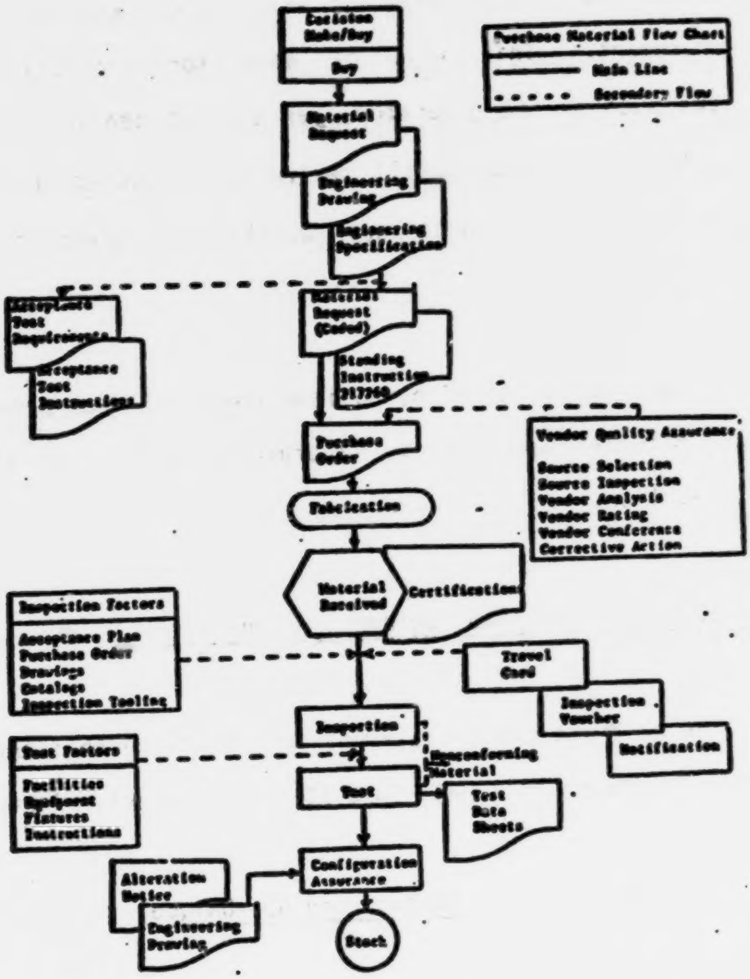
Decision
Make/Buy
Buy
Purchase Material Flow Chart
Main Line
Secondary Flow
Material
Request
Engineering
Drawing
Engineering
Specification
Acceptance
Test
Requirements
Acceptance
Test
Instructions
Material
Request
(Coded)
Standing
Instruction
217360
Purchase
Order
Vendor Quality Assurance
Source Selection
Source Inspection
Vendor Analysis
Vendor Rating
Vendor Conference
Corrective Action
Fabrication
Material
Received
Certification
Inspection Factors
Acceptance Plan
Purchase Order
Drawings
Catalogs
Inspection Tooling
Travel
Card
Inspection
Voucher
Notification
Inspection
Nonconforming
Material
Test Factors
Facilities
Equipment
Fixtures
Instructions
Test
Test
Data
Sheets
Alteration
Notice
Engineering
Drawing
Configuration
Assurance
Stock

Figure 2. PURCHASED MATERIAL FLOW CHART (TYPICAL)

3.4.2 NON-UNIQUE ITEMS

Normally, non-unique items and materials will be procured to industry, military, or catalog item standards. In the event that Engineering and/or Reliability deems it necessary, in order to satisfy program requirements, specifications or source control drawings will be prepared and used as the basis for procurement. This will be done for critical, long lead, non-standard items such as the generator, yaw and hub bearings, transformers, controls, etc. Product Assurance will review all procurement documents and insure incorporation of the necessary quality requirements into these documents.

Material used in the fabrication of non-unique items will not normally require analysis by the Material and Process Laboratory, unless specified by the drawing or specification.

3.5 GOVERNMENT SOURCE INSPECTIONS (Unique and Non-Unique)

All purchase orders will include a statement to the effect that the government reserves the right to inspect all materials at the supplier's plant.

3.6 GOVERNMENT FURNISHED PROPERTY (Unique and Non-Unique)

Government furnished property will be controlled and stored under suitable conditions to protect it from loss or damage. Any damage to government property will be reported to NASA-LeRC and the cause and extent of damage will be investigated.

3.7 MATERIAL IDENTIFICATION, HANDLING AND STORAGE (Unique and Non-Unique)

3.7.1 MATERIAL IDENTIFICATION

All materials including critical high cost, long lead unique items such as the yaw bearing, blades, gearbox, etc. will be identified according to their respective engineering definitions. Identification will be on the material and/or documentation that is traceable to the material. Material will be further identified by serial or lot numbers when practical. Upon completion of inspection and/or test, the material will be identified as "accepted" or "rejected" by stamping the item and/or its associated documentation.

3.7.2 HANDLING AND STORAGE

Standard procedures now in effect will be used, as applicable, on the MOD-5A WTG program. Procedures for the controls imposed on storage, handling, preservation and shipping will be patterned after existing procedures.

Any additional procedures or deviations from existing procedures will be reviewed by the PAE prior to their implementation.

3.8 RAW MATERIALS CONTRCL (Unique)

3.8.1 RAW MATERIAL FOR UNIQUE HARDWARE

Material used in the fabrication of the WTG Unique Hardware will be identified by type, lot number, heat number, or serial numbers as appropriate, and as specified in drawings, specifications and procurement documents.

3.8.2 CHEMICAL/PHYSICAL TEST DATA

Chemical/Physical Test Data supplied by accredited suppliers will be used normally to certify material properties. Chemical/Physical tests on materials will be conducted internally or by independent laboratories when specifically required by drawings or specifications.

3.9 INSPECTION AND TEST (Unique)

3.9.1 INSPECTION OF UNIQUE HARDWARE

Inspection of unique hardware will be to requirements of engineering specifications and drawings as detailed in written inspection planning.

The PAE, together with the responsible Design Engineer, will determine the necessary inspections to assure that all articles meet the requirements specified in the drawings and specifications.

The requirements for inspections will be specified in all procurement documents, as will the documentation required to prove successful completion of these inspections.

Critical high cost, long lead items such as the gearbox, generator, yaw bearings, main rotor bearing, etc. will have critical inspections witnessed and verified at the suppliers plant, as directed by the PAE and specified in the procurement documents.

The PAE will be responsible for verifying the completion of fabrication and processing operations, and the accuracy and completeness of required documentation by review of inspection records.

3.9.2 INSPECTION OF NON-UNIQUE HARDWARE

The majority of non-unique procured items will be standard commercial or industrial hardware and catalog items. Unless specified otherwise in specifications or drawings the procurement documents will not specify any inspections or test by the supplier other than his standard factory inspections and tests. GE receiving inspection will inspect for completeness of the order, shipping damage, conformance to catalog requirements and specified documentation.

Non-Unique articles fabricated and assembled at GE will be inspected to written planning integrated with manufacturing planning. Characteristics designated for recording as variables data will be defined in the planning. In addition, any requirements for special tools, gages or fixtures will be determined and specified. A typical flow of documentation and events in fabrication and assembly is shown in Figure 3.

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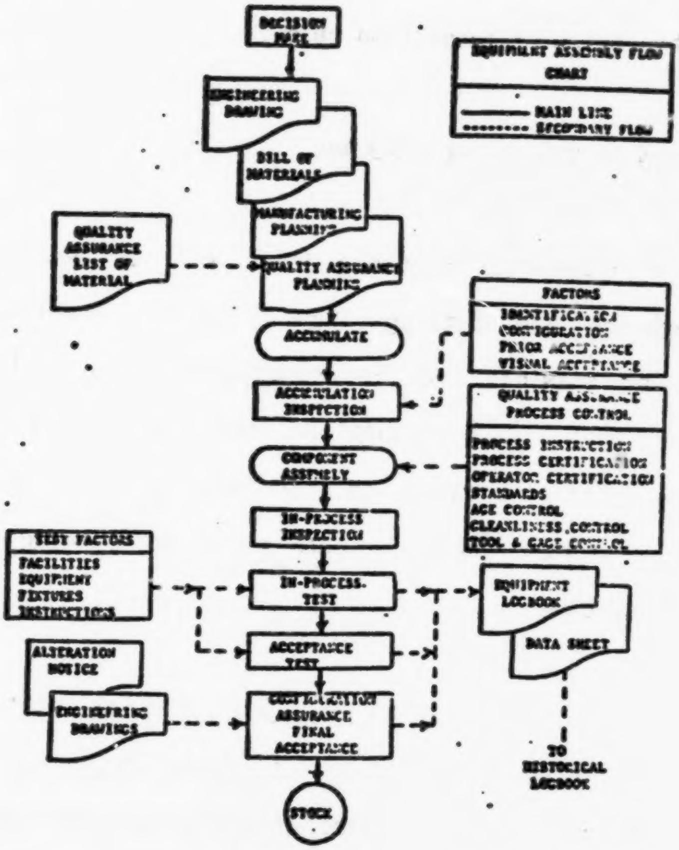
DECISION MAKE
EQUIPMENT ASSEMBLY FLOW CHART
MAIN LINE
SECONDARY FLOW
ENGINEERING DRAWING
BILL OF MATERIALS
MANUFACTURING PLANNING
QUALITY ASSURANCE LIST OF MATERIAL
QUALITY ASSURANCE PLANNING
ACCUMULATE
FACTORS
IDENTIFICATION
CONFIGURATION
PRIOR ACCEPTANCE
VISUAL ACCEPTANCE
ACCUMULATION INSPECTION
QUALITY ASSURANCE PROCESS CONTROL
PROCESS INSTRUCTION
PROCESS CERTIFICATION
OPERATOR CERTIFICATION
STANDARDS
AGE CONTROL
CLEANLINESS CONTROL
TOOL & GAGE CONTROL
COMPONENT ASSEMBLY
IN-PROCESS INSPECTION
TEST FACTORS
FACILITIES
EQUIPMENT
FIXTURES
INSTRUCTIONS
IN-PROCESS TEST
EQUIPMENT LOGBOOK
DATA SHEET
ACCEPTANCE TEST
ALTERATION NOTICE
ENGINEERING DRAWINGS
CONFIGURATION ASSURANCE FINAL ACCEPTANCE
TO HISTORICAL LOGBOOK
STOCK

Figure 3. TYPICAL FABRICATION OR ASSEMBLY FLOW CHART

3.9.3 SYSTEMS TESTS

Systems tests will be performed in accordance with written Standing Instructions. Product Assurance will monitor the tests and will be an integral part of the Test Readiness Review Team. The Test Readiness Review Team consisting of personnel from Engineering, Product Assurance and Test have the responsibility for reviewing procedures, facility, personnel requirements, availability of safety requirements and procedures, and availability and operability of equipment prior to initiation of test.

Systems test will include the calibration and check out of the complete instrumentation link. Sensors, corresponding indicators, and their associated signal sources or power supplies will be checked out and calibrated. Periodic recalibration requirements will be imposed on those individual items where it is feasible and deemed to be beneficial. Ordinary commercial panel meters and quick-look, non-critical gauges will not be subjected to periodic calibration.

3.10 PROCESS CONTROL (Unique)

Special Processes, metallurgical, chemical and physical tests performed at GE and subcontractors will be performed to written procedures by qualified operators. General Electric operates a "Process Readiness" and "Operator Certification" program to insure the process is fully proven and that operators are appropriately qualified prior to application of the process to deliverable equipment.

General Electric will insure that procured parts are processed using developed processes and skilled operators. Existing QAP's establish procedures for specifying, reviewing and approving supplier special processes certifications. Critical processes being performed at a suppliers facility will be monitored by General Electric personnel as deemed necessary by the PAE in coordination with the responsible Design Engineer.

The work statement, specification, or purchase order will specify the documentation and controls necessary to insure satisfactory evidence of the end item quality.

3.11 NON-CONFORMING ARTICLES (Unique and Non-Unique)

3.11.1 GENERAL

Any deliverable material, part, or assembly in which one or more characteristics do not conform to the requirements specified in the contract, specification, drawing or other applicable document shall be designated as non-conforming material. All non-conformances, with the exception of subcontractor or vendor supplied material, will be initially documented on a defect report (DR) (Figure 4). Subcontractor/supplier supplied material will be documented on a Non-Conformance Report only (Figure 5).

All non-conforming material will be identified and controlled until disposition is made and corrective action taken. The system is illustrated in Figure 6. Disposition of non-conformances shall be based on engineering assessments of the ability of the non-conforming item to perform its intended function.

3.11.2 MATERIAL REVIEW

An initial review of the non-conforming material (DR) will be made by the responsible Product Assurance Engineer and Design Engineer and classified into two categories. The first is material that can be reworked to conform to the applicable drawing or specification requirements. Disposition of material in this category will be made on the "floor" by the Quality Control & Design Engineers.

The second category is material that cannot be "reworked" or completed to conform to the applicable requirements. A Non-conformance report (Figure 5) will be prepared for this category, and the material and report forwarded for Material Review Board (MRB) action.

3.11.2.1 Reworkable Material

When inspection reveals a non-conformance that can be corrected through "rework" or "completion" of the material, the material shall be identified to indicate its non-conformance. Upon correction of the non-conformance, the material shall be resubmitted for inspection.

3..11.2.2 Non-reworkable Material

Non-reworkable material shall be identified as non-conforming and placed in a controlled area which segregates it from other material. A non-conformance report shall be submitted to the "Material Review Board" (MRB) for review and disposition.

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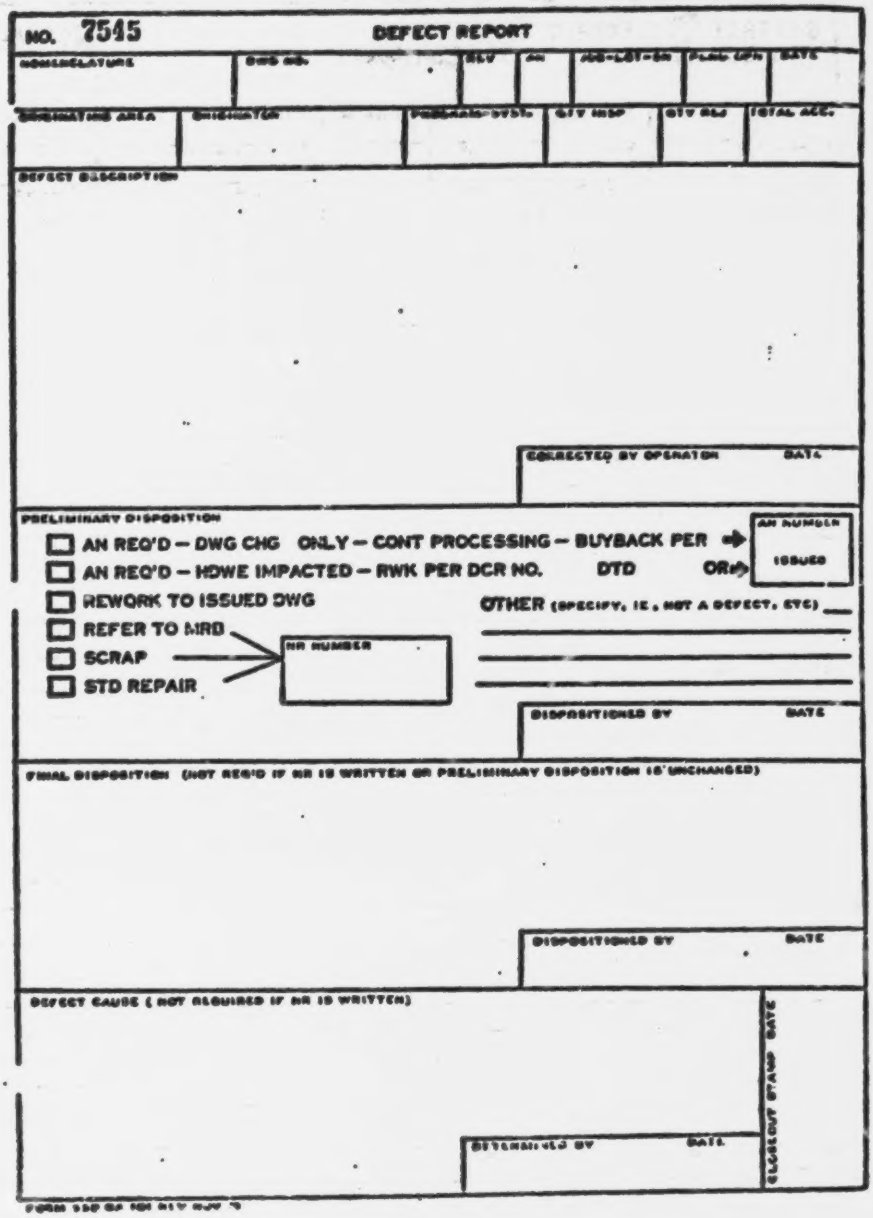

NO. 7545 DEFECT REPORT

NOMENCLATURE	DWG NO.	ELV	AN	[illegible]	[illegible]	DATE

ORIGINATING AREA	ORIGINATOR	PROGRAM-SYST.	QTY INSP	QTY REJ	TOTAL ACC.

DEFECT DESCRIPTION

CORRECTED BY OPERATOR DATE

PRELIMINARY DISPOSITION

☐ AN REQ'D – DWG CHG ONLY – CONT PROCESSING – BUYBACK PER →
☐ AN REQ'D – HDWE IMPACTED – RWK PER DCR NO. DTD OR →

AN NUMBER
ISSUED

☐ REWORK TO ISSUED DWG
☐ REFER TO MRB
☐ SCRAP
☐ STD REPAIR

NR NUMBER

OTHER (SPECIFY, IE., NOT A DEFECT, ETC) ___

DISPOSITIONED BY DATE

FINAL DISPOSITION (NOT REQ'D IF NR IS WRITTEN OR PRELIMINARY DISPOSITION IS UNCHANGED)

DISPOSITIONED BY DATE

DEFECT CAUSE (NOT REQUIRED IF NR IS WRITTEN)

DETERMINED BY DATE

CLOSEOUT STAMP DATE

FORM [illegible]

Figure 4.

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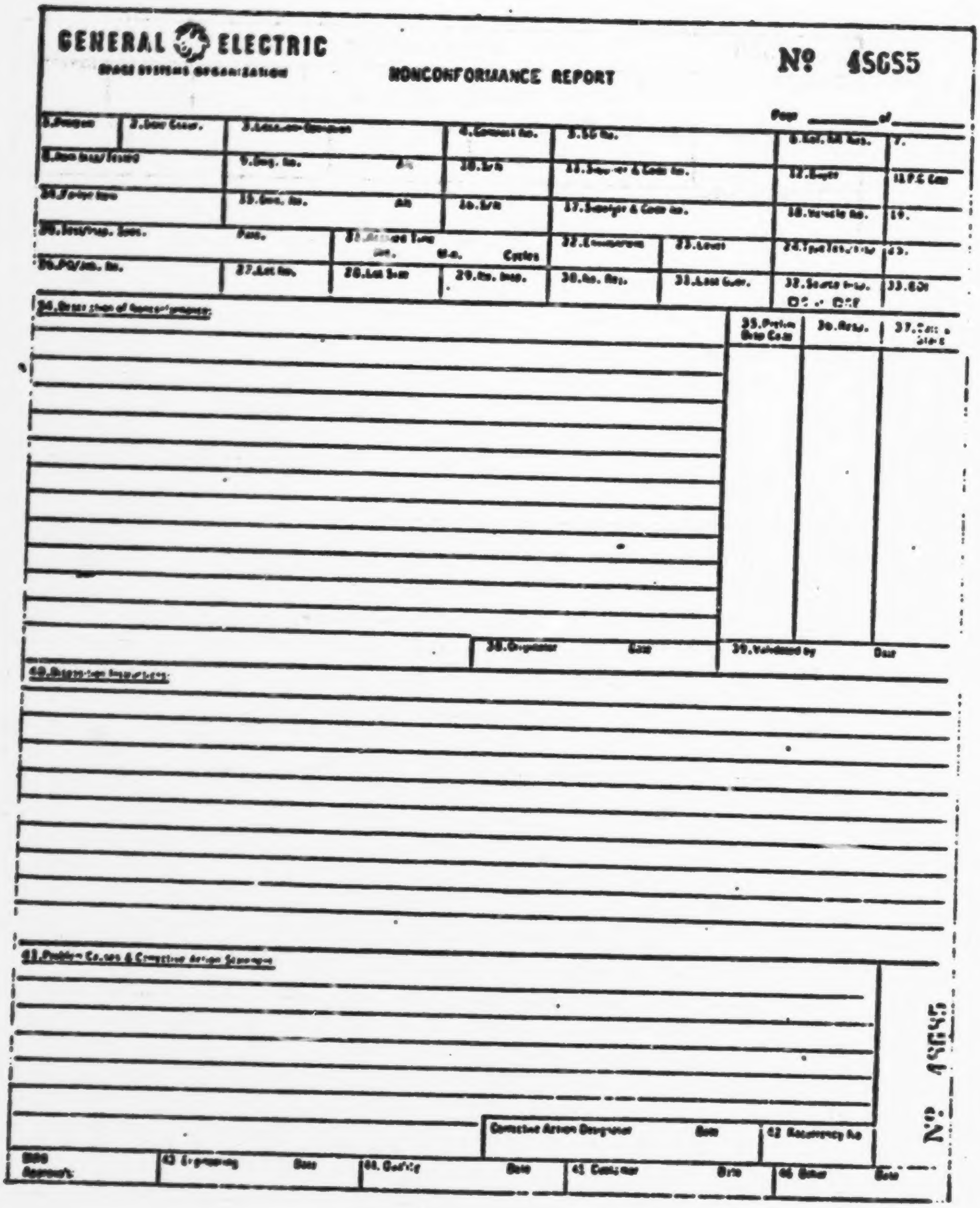

GENERAL ELECTRIC

NONCONFORMANCE REPORT

Nº 4SGS5

Figure 5.

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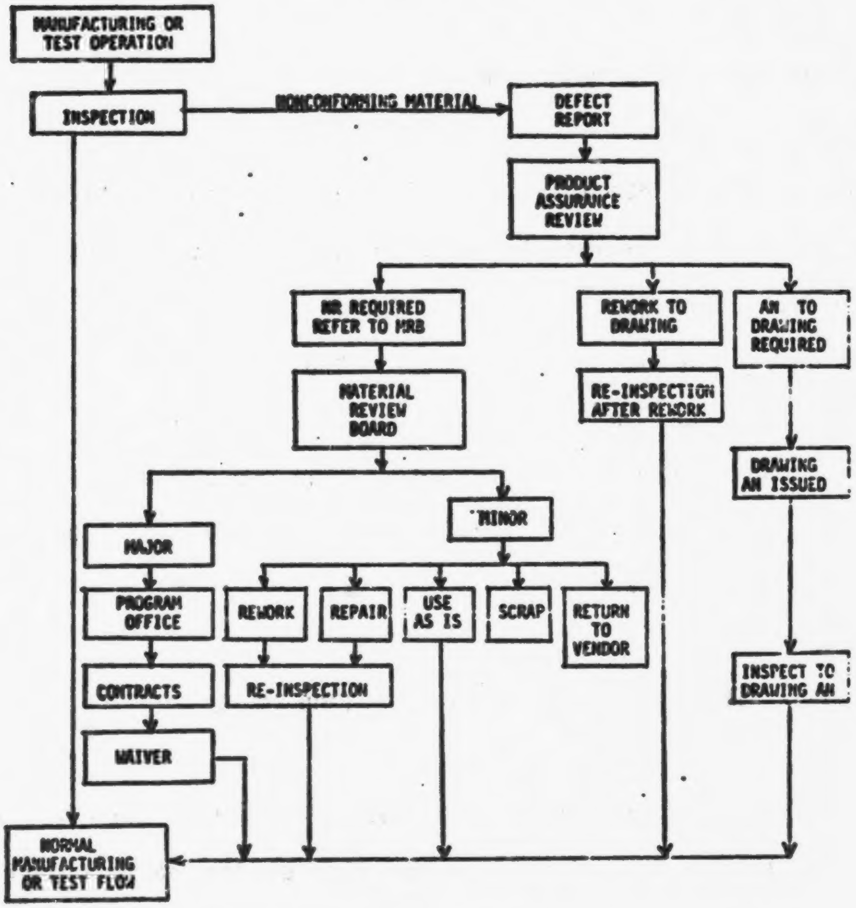
MANUFACTURING OR TEST OPERATION
INSPECTION
NONCONFORMING MATERIAL
DEFECT REPORT
PRODUCT ASSURANCE REVIEW
MR REQUIRED REFER TO MRB
REWORK TO DRAWING
AN TO DRAWING REQUIRED
MATERIAL REVIEW BOARD
RE-INSPECTION AFTER REWORK
DRAWING AN ISSUED
MINOR
MAJOR
PROGRAM OFFICE
REWORK
REPAIR
USE AS IS
SCRAP
RETURN TO VENDOR
CONTRACTS
RE-INSPECTION
INSPECT TO DRAWING AN
WAIVER
NORMAL MANUFACTURING OR TEST FLOW

Figure 6. NONCONFORMING MATERIAL FLOW

The material will then be processed in accordance with the MRB disposition and identified accordingly. Disposition may be either "use as is", return to vendor, scrap or repair. If repair is indicated, the repair and inspection procedures shall be approved by the MRB prior to implementation. Records of all non-conformances, their disposition, and corrective action taken shall be maintained.

3.11.3 MATERIAL REVIEW BOARD (MRB)

The Material Review Board shall consist of one representative from GE Design Engineering, and one representative from Quality Control Engineering (who will serve as MRB Chairman). The Review Board shall convene to review and make disposition of non-conforming material. The disposition shall be by mutual agreement based on the ability of the hardware to perform its intended function. The responsibility for authorizing subcontractor and supplier MRB action shall lie with GE. MRB authority will not be delegated to subcontractor/suppliers.

3.11.4 NASA NOTIFICATION AND/OR PARTICIPATION IN MRB

On any non-conformances that may adversely affect safety, reliability, durability, performance, interchangeability, or the basic objectives of the contract, one copy of the "NR" and the Review Board disposition shall be submitted to the NASA/LeRC Project Manager for his approval within five (5) working days after the decision. General Electric will be notified in writing of any NASA/LeRC disapprovals. This notification will be made within five (5) working days after NASA/LeRC receipt of the "NR". As delineated in this Quality Plan, applicable portions of the existing QAP's will be used.

3.11.5 LOG BOOK

One copy of each "DR", "NR" and other Review Board documentation shall be maintained by Quality Control for inclusion in the Equipment Log.

3.12 INSPECTION, MEASURING, AND TEST EQUIPMENT CONTROL (Unique and Non-Unique)

3.12.1 GENERAL

Control of gages, standards, measuring equipment, and test equipment shall be in accordance with existing procedures.

3.12.2 CALIBRATION

All inspection, measuring, and test equipment is periodically calibrated against standards that are traceable to the National Bureau of Standards (NBS). Records are maintained in the form of punched card listings and all equipment bears a calibration sticker which indicates the date when calibration was last performed, when next calibration is due, and the Inventory Control Number of the equipment. In addition to internal controls on calibration of equipment and instrumentation, these requirements will be imposed on subcontractors and outside suppliers. All inspection equipment and test instrumentation will require periodic calibration to standards traceable to the NBS. Data compiled with other than currently calibrated equipment or instrumentation will not be considered acceptable. Ordinary commercial or industrial grade instruments such as pressure gages, panel meters (volts, amps, etc.), thermometers and the like, normally used as functional indicators only, will not be subjected to periodic calibration. These items will be functionally checked as part of the hardware and system check-out.

3.12.3 CALIBRATION FACILITIES AND STANDARDS

The GE Calibration Laboratory has standard industrial air conditioning for controlling temperature. The relative humidity does not exceed 55 percent and dust is controlled by the use of filters in the air supply and by selective use of dust covers on equipment. Within state-of-the-art limitations, the accuracy ratio of the calibrating standard to the instrument being calibrated will be maintained between 4 and 10 to 1; the accuracy ratio of the calibrated equipment with respect to the characteristic being measured will be 10 to 1 where possible.

3.12.4 EQUIPMENT EVALUATION

Special equipment (e.g. automatic test and checkout equipment) shall be evaluated to determine its accuracy and tolerance capability to provide the desired indications or records, its compatibility with the articles to be inspected or measured and the correctness and completeness of operating instructions.

3.12.5 MAINTENANCE AND CONTROL

Periodic inspection, maintenance and recalibration of equipment shall be performed at specified intervals. The intervals shall be predetermined in accordance with the individual requirements of the equipment as determined by:

a. Frequency of use
b. Required accuracy
c. Type of equipment
d. Other conditions affecting its ability to measure

Equipment which proves to be faulty shall be identified as defective and removed from service until corrective action has been taken. Hardware identified as having been inspected/tested using discrepant measuring equipment will be documented on a Defect Report and will require disposition by Product Assurance and Design Engineering prior to acceptance for use.

3.12.6 WRITTEN PROCEDURES

Calibration and maintenance procedures are prepared for all test equipment and will be available for review by NASA/LeRC.

3.12.7 RECORDS

Records will be maintained for all inspection, measuring, and test equipment, including such information as current location and custodian, calibration status, preventive maintenance dates, etc.

3.13 INSPECTION STATUS INDICATION (Unique and Non-Unique)

3.13.1 GENERAL

The General Electric AEPD maintains a system for the use of inspection stamps to indicate the inspection/test status of all hardware. In instances where hardware cannot be physically stamped, a stamped identification card will be attached or enclosed in the package. In addition, documentation such as purchase orders, travel tags, data sheets, and inspection planning are stamped to indicate hardware status.

3.14 PRESERVATION, PACKAGING AND SHIPPING (Unique and Non-Unique)

GE-AEPD, subcontractors for unique items, and other suppliers, when so specified on purchase orders or work statements, will prepare written procedures for the preservation, packaging and shipping of articles in a manner to provide protection of hardware throughout the length of the contract and to prevent damage, loss, deterioration, degradation or substitution. Other hardware will be packaged and shipped in accordance with good commercial practices. All required shipping and technical documents including handling instructions, operating instructions, end-item reports, drawings, parts lists, test data and approved waivers will accompany each shipped item as applicable.

All articles shipped by GE will be inspected prior to shipment to assure that they are: completed units; adequately packed and preserved; properly identified; that all required documentation accompanies the article.

3.15 INSPECTION AND TEST RECORDS (Unique and Non-Unique)

Integrated manufacturing and inspection planning provides complete documented inspection results. Test instructions detail test requirements and data to be recorded. Any deviations or anomalies are recorded on "DR" sheets and/or NR's. All inspection and test data will be made available to NASA/LeRC upon request.

3.16 EQUIPMENT LOG (Unique and Non-Unique)

A separate log will be established and maintained for each WTG as a means of documenting the continuous manufacturing, test and inspection history. Logs will be identified with the equipment to which they pertain, will be maintained in chronological order, will account for all periods of time or any movement of the item and will accompany the item. They will include: Certification of Compliance, Shipping Document, List of Materials (as built), DR Sheets, NR Reports, Test Data, and Significant Events Log.

3.17 FAILURE REPORTING (Unique)

Non-conformance Reports will be generated at the final performance test level of unique items, major items (gearbox, generator, brake hydraulic systems) and the WTG by System Test Personnel and will reflect all out of specification test conditions and results. NASA/LeRC will be notified by letter containing a copy of the NR for each functional failure. This report will contain the analysis of the failure, recommended corrective action and corrective action taken.

The initial NR will state the symptoms of the problem. Subsequent analysis, disposition, and corrective action will be added after the problem is investigated by the Product Assurance Engineer, Design/System Engineer, and Program Management where applicable.

The responsible Design Engineer will complete the diagnosis of the problem and is required to initiate corrective action.

The NR and associated documentation will be made available to NASA/LeRC and a copy will accompany the hardware on delivery.

The failures occurring during each month shall be summarized in the Monthly Narrative Status Report, and the status of open NR's from previous monthly reports will be updated. Failures of a repetitive nature, even on minor non-unique items, will be included in the Monthly Status Report.

3.18 CLEANLINESS CONTROL

General Electric maintains cleanliness controls on manufacturing areas, test areas, inspection and storage areas. It is anticipated that the majority of Wind Turbine manufacturing assembly and test will be conducted in "standard" areas. "Standard" areas are defined as those areas subject to routine cleanliness/housekeeping requirements only, and include the following specific requirements:

- There shall be no eating, drinking of beverages, or smoking in the areas.
- Hardware not in the fabrication cycle must be adequately protected against dirt or contamination.
- Good housekeeping practices shall be followed and shall include, but not be limited to, the following:
  - Floors, storage racks, test equipment, work benches, lockers, and cabinet tops shall be dusted regularly; suitable containers shall be provided for refuse which is generated during processing operations. Work area and benches shall be cleaned upon completion of work performed.

3.19 RADIOGRAPHIC INSPECTION (Unique)

Unique and Non-unique items, will be subjected to radiographic inspection in accordance with the requirements specified in test/inspection procedures and as determined by Design Engineering and Reliability Engineering. Inspection records will be maintained at GE-AEPD and/or its subcontractors. Records shall be available for review by NASA-LeRC at the specific maintenance sight.

3.20 PRODUCTION INSPECTION FLOW DIAGRAM

A preliminary production flow diagram indicating inspection points in the cycle is included in Figure 7. As design progresses and details become available, the diagram can be updated to indicate inspection and test points in greater detail.

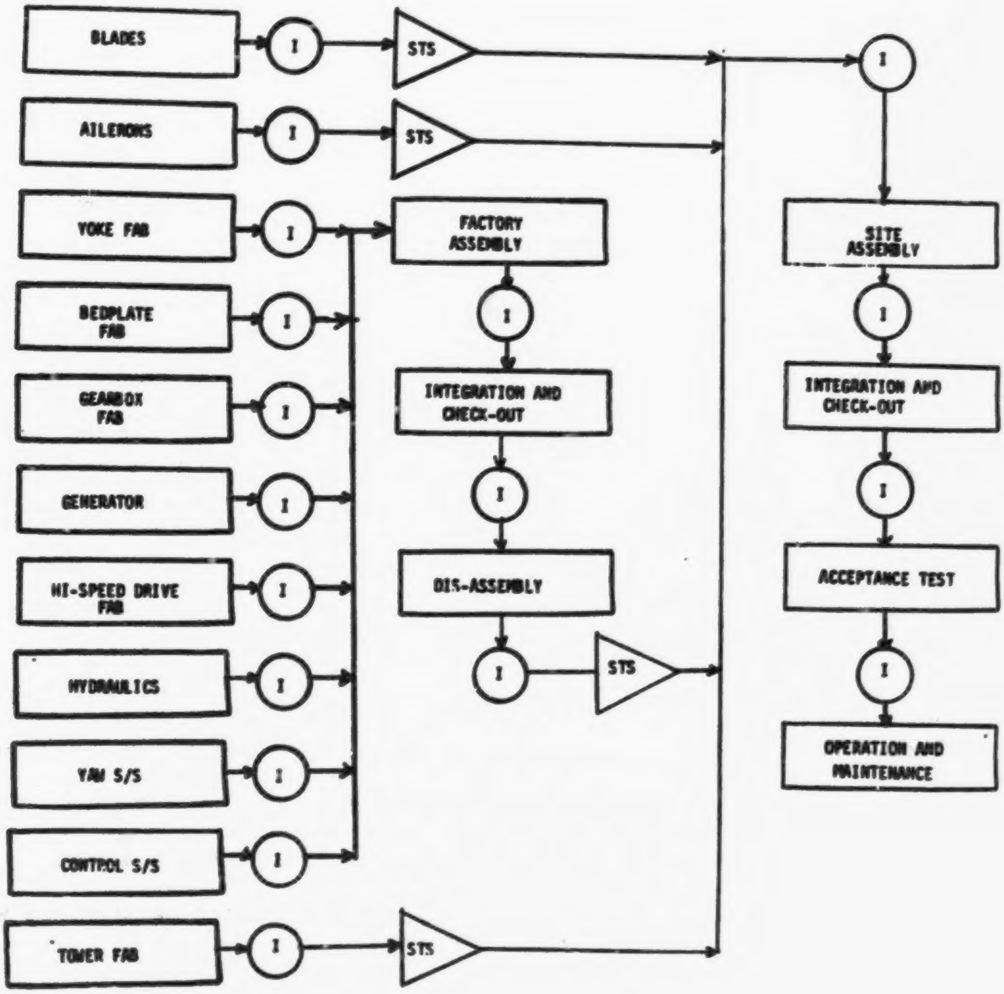
BLADES
AILERONS
YOKE FAB
BEDPLATE FAB
GEARBOX FAB
GENERATOR
HI-SPEED DRIVE FAB
HYDRAULICS
YAW S/S
CONTROL S/S
TOWER FAB
I
STS
FACTORY ASSEMBLY
INTEGRATION AND CHECK-OUT
DIS-ASSEMBLY
SITE ASSEMBLY
INTEGRATION AND CHECK-OUT
ACCEPTANCE TEST
OPERATION AND MAINTENANCE

Figure 7. PRODUCTION/INSPECTION FLOW DIAGRAM

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APPENDIX C
GE - SYSTEM SAFETY PLAN FOR THE MOD-5A PROGRAM

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SYSTEM SAFETY PLAN
FOR THE
MOD-5A WIND TURBINE GENERATOR PROGRAM

REV "B"
MAR. 84

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REVISION LOG

This log identifies those portions of this document which have been revised since original issue. revised portions of each page, for the current revision only, are identified by marginal striping or text notes.

Revision	Page No.	Paragraph Number(s) Affected	Rev. Date	Approval
A	All	General rewrite to incorporate NASA review comments.	5-1-81	A. Cheddar
B	All	Assign document control number and issue. Change page numbering. Correct typographical errors.	3-15-84	A. Cheddar

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SECTION 1.0

SCOPE

This plan defines the requirements to be implemented to insure product and personnel safety during all phases of the MOD-5A WTG Program. It applies to design, development, production, factory test and evaluation and to the assembly, operation and support at the WTG site location.

By agreement with the General Electric Space Division, GE, AEPD will use the GE, Valley Forge Space Center Safety Manual. This document is referenced in this plan and copies of pertinent instructions and/or procedures are included in the Appendix.

SECTION 2.0

PURPOSE

The purpose of this plan is to insure that:

a. Safety consistent with the program objectives is designed into the WTG system.

b. Potential hazards inherent in the system are identified and evaluated and that action required to eliminate or control them within acceptable limits is taken.

c. Proven designs and materials are used where feasible and new designs and materials are fully evaluated to minimize risks.

d. Changes or modifications to the system do not compromise the level of safety inherent in the system.

e. Production, assembly and test methods, equipment and facilities will not degrade the level of safety designed into the system.

SECTION 3.0

POLICY

It is the policy of the WTG Program to provide the equipment and environment that provides maximum safety for personnel and equipment during all operations and applications, and to take all required measures to eliminate, within the limits of controllable hazards, the risk of injury or damage to personnel or equipment during all phases of the WTG Program.

Full adherence to GE Corporate and Space Division Policies on Safety, applicable industry standards, federal and local regulatory requirements, technological developments, and contractual requirements shall be maintained at all times.

SECTION 4.0

APPLICABLE DOCUMENTS

4.1 GENERAL ELECTRIC DOCUMENTS

1. General Electric Corporate Executive Office - Organization and Policy Guide 20.12 - Product Safety.
2. General Electric Corporate Executive Office - Organization and Policy Guide 20.14 - Employee Health and Safety.
3. General Electric Valley Forge Space Center Safety Manual.
4. General Electric Space Division Policy 7.1 - Employee Health and Safety.

4.2 OTHER DOCUMENTS

1. Occupational Safety and Health Act of 1970.
2. (TBD) State Safety Code.
3. NASA PR 1.5204 (d).
4. Code of Federal Regulations, Title 29, Parts 1910 and 1926.

SECTION 5.0

RESPONSIBILITIES

5.1 MANAGER - MOD-5A WTG PROGRAM

The Manager of the MOD-5A WTG Program has overall responsibility for the safety and performance of the MOD-5A WTG Program. He will define the top level organization roles and responsibilities, lines of authority and limitations as it applies to program/product safety and will also participate in Safety Review Board Meetings and all Design Reviews.

5.2 MANAGER - MOD-5A WTG SYSTEMS ENGINEERING

The Manager of MOD-5A WTG Systems Engineering is responsible for assuring that the WTG System Requirements minimize the possibility that a failure or malfunction will create a hazardous or catastrophic condition that can affect personnel or WTG equipment safety. He is also responsible for designing a system concept that provides for adequate personnel and equipment protection throughout the test and operational phases of the Program. In addition, he will participate in all Design Reviews.

5.3 MANAGER - MOD-5A DESIGN ENGINEERING

The manager of MOD-5A WTG Design Engineering is responsible for assuring that the designs for the individual subsystems, subassemblies and components are compatible with the overall system concept and that risk that the failure of any of these subtier components will jeopardize the overall system objectives will be below acceptable levels. In addition to the above, he will participate in Safety Review Board Meetings and all Design Reviews.

5.4 MANAGER - MOD-5A WTG HARDWARE INTEGRATION

The manager of MOD-5A WTG Hardware Integration is responsible for the manufacturing and assembly aspects of the program, for quality assurance, reliability and FMEA, and for systems integration, installation and test. His function is to insure that the safety level designed into the system is not compromised during the production and test stages of the program. In addition to the above, he will:

- Serve on the Safety Review Board
- Participate in Design Reviews
- Coordinate assembly and test facility requirements
- Provide for assembly and test personnel training

5.5 PRODUCT AND SAFETY ASSURANCE ENGINEER - MOD-5A WTG PROGRAM

The Product and Safety Assurance Engineer assigned to the MOD-5A program is responsible for insuring that the detailed requirements specified in the MOD-5A Safety Plan are implemented and adhered to by the responsible program personnel. He will interface with the managers of the various MOD-5A WTG operations and with the Space Division Manager of Industrial Safety and Hygiene on all matters relating to system and personnel safety. In addition to the above, he will:

- Serve on the Safety Review Board
- Participate in Design Reviews
- Prepare facility safety checkoff list
- Act as the Safety Monitor during all phases of assembly, checkout and test.

5.6 MANAGER - MOD-5A WTG SUBCONTRACTS AND PROCUREMENT

The Manager of the MOD-5A WTG Subcontracts is responsible to insure that safety requirements are imposed on each major subcontractor through the subcontract SOW. Each major subcontractor is to prepare a safety plan for review and approval by the GE MOD-5A Product and Safety Assurance Engineer. This safety plan will identify each feature of the design which could cause hazardous conditions or catastrophic failures and will outline the procedures to be followed to eliminate these conditions or to reduce them to a level acceptable to GE and the customer.

5.7 MOD-5A WTG TEST CONDUCTOR/TEST FOREMAN

During factory test, a Test Conductor/Test Foreman will be in charge of testing. He is responsible for assuring that procedures are followed and safety requirements are adhered to. The Test Conductor shall have the authority to approve procedure variations for troubleshooting and test expediency. All variations will be recorded on the Procedure Variation Sheet and approved by the Test Conductor and the Product and Safety Assurance Engineer.

5.8 MOD-5A GE-AEPD SITE MANAGER

The GE-AEPD Site Manager has overall responsibility for safety during construction, erection and checkout at the WTG site. He will insure that potential hazards have been identified, that procedures to prevent injury to personnel or damage to equipment have been prepared and that these procedures are followed. He will verify that site subcontractors are in full compliance with local, state and federal safety regulations and will also serve as a member of the site Safety Review Board.

5.9 MOD-5A SUBCONTRACTOR SITE MANAGER

The Subcontractor Site Manager is responsible for insuring that all work performed by the subcontractor complies with local, state and federal regulations. He shall prepare safety procedures for review by the GE-AEPD Site Manager. He is responsible for obtaining all permits, licensing and/or certifications required by local, state or federal regulations and will serve as a member of the site Safety Review Board.

5.10 MOD-5A WTG SAFETY REVIEW BOARD

The MOD-5A Safety Review Board is responsible for insuring that specified safety requirements or procedures have been implemented in each phase of the program prior to the commencement of any operations involving hardware in that phase. The Board's approval of procedures, equipment, facilities and the level of personnel training and competence is required before any operations may proceed.

The MOD-5A Safety Review Board shall consist of the following:

1. MOD-5A Product and Safety Assurance Engineer - Chairman.
2. Manager - MOD-5A WTG Design Engineering.
3. Manager - MOD-5A WTG Hardware Integration.
4. Manager - MOD-5A WTG Program.

5.11 DELEGATION OF RESPONSIBILITY

Each of the above managers has the authority to delegate portions of his responsibility to individuals within his operation. The ultimate responsibility, however, for all aspects of safety within his operational jurisdiction remains with the individual operation manager.

SECTION 6.0

DESIGN AND DEVELOPMENT

WTG equipment and personnel safety has its foundation in the design of the product. The WTG will be designed to minimize the probability that a failure will create a hazardous or catastrophic condition that can affect WTG equipment or personnel safety.

6.1 PROGRAM CONTROLS

The disciplines and program controls which will be applied during the design and development phases of the Program to insure product and personnel safety include:

6.1.1 FMEA

An FMEA will be completed during the Preliminary Design Phase which will identify potential hazards inherent in the design. Hazards will be evaluated and the necessary steps taken to eliminate them or to reduce them to an acceptable level. The FMEA will be updated during the Final Design Phase to assess the effects of design changes or modifications.

6.1.2 DESIGN ANALYSES

Design analyses will be performed in the areas of stress, fatigue, dynamics and control stability. New designs and materials will be evaluated. Tests and validation requirements to verify that the designs meet operating and environmental requirements will be identified. Results and recommendations of the analyses will be documented.

6.1.3 DESIGN REVIEWS

Formal design reviews, attended by participants from GE and NASA, will be held at the end of the Conceptual, Preliminary and Final Design Phases. Representatives from Engineering, Manufacturing, Product Assurance, Reliability and Safety will participate in these reviews. In addition to these reviews, informal design reviews will be performed on a continuing basis prior to the issuance of each drawing and specification. Review and approval of these documents is required by Design Engineering, Manufacturing and Product Assurance.

6.1.4 INDEPENDENT SAFETY REVIEW

During the Final Design Phase, a safety review of the RAM and FMEA analyses will be performed by an independent review board designated by the Manager - Wind Turbine Programs. This independent review board will be staffed by senior representatives of the various departmental operations who are not members of the MOD-5A WTG team.

SECTION 7.0

ASSEMBLY AND TEST FACILITY

The WTG Assembly and Test Facility will be reviewed by the WTG Product and Safety Assurance Engineer and the Manager - WTG Hardware Integration to verify that the facility provides the equipment, personnel safety and security that is required.

7.1 FACILITY SAFETY REVIEW

Prior to commencing any assembly or test operations in the facility, a Facility Safety Review will be performed by the MOD-5A Safety Review Board. This review will be made, using a comprehensive checkoff list prepared by the WTG Product and Safety Assurance Engineer and the Manager, MOD-5A Hardware Integration, which includes those items necessary for a safe and expeditious assembly of the MOD-5A WTG. This review will assure the facility meets the following broad criteria:

1. Adequate building security including fire protection and alarms.
2. Secure and adequate equipment storage facilities.
3. Adequate and safe utility supplies:
    a) Electrical
    b) Heating
    c) Sanitary
    d) Water

4. Adequate and safe crane facilities:

    a) Cranes will be proof loaded to at least 1.5 times the maximum load to be lifted.

    b) Cranes will be proof loaded at least once per year.

    c) Cranes shall be inspected carefully for damage or wear prior to each major lift.

    d) The Manager - MOD-5A Hardware Integration, the MOD-5A Product and Safety Assurance Engineer, or the assembly foreman may require special inspections and/or proof loading of cranes should they deem this necessary or beneficial.

5. Adequate floor loading capabilities and foundations to support WTG equipment during assembly and test operations.

6. Access for personnel and equipment.

7. Adequate space for storage, assembly, test and shipping operations.

SECTION 8.0

SYSTEM ASSEMBLY, DISASSEMBLY AND SHIPPING

8.1 SYSTEM ASSEMBLY, DISASSEMBLY AND SHIPPING

System assembly, disassembly and shipping will require potentially hazardous operations to personnel and equipment. Included are:

1. Movement and lifting of large, heavy equipment.
2. High voltage electrical connections.
3. High pressure hydraulic systems.
4. Rotating equipment.

8.2 ASSEMBLY, DISASSEMBLY AND SHIPPING PROCEDURES

All assembly, disassembly and shipping operations will be performed to written instructions/procedures prepared by WTG Manufacturing and approved by WTG Design Engineering. These procedures will describe the equipment, facilities, personnel requirements, interfaces and connections in addition to the operations necessary to assemble the MOD-5A. They shall be reviewed by the WTG Product and Safety Assurance Engineer.

8.3 TOOLING AND FIXTURE CHECKOUT

Prior to the start of assembly operations, the conformance of all special fixturing and tooling to specified requirements will be verified. All lifting slings, cables and chains will be proof-loaded to drawing requirements prior to use in the WTG assembly operations and will be marked or tagged to indicate proof load and date tested.

8.4 ASSEMBLY SAFETY REVIEW

Prior to start of assembly operations, a Safety Review will be conducted by the MOD-5A Safety Review Board. This review will verify:

1. All safety and security devices, signs and procedures are implemented and operational.
2. All personnel have been trained in the assembly sequence, procedures and special precautions.
3. All tooling and handling equipment are available and have been verified to satisfy applicable requirements.
4. The test and assembly facility has been prepared for the assembly operation, potential hazards have been eliminated and adequate protection and warning signs have been installed.
5. Personnel access lists have been prepared and are posted and personnel safety equipment (hardhats, safety shoes, and safety glasses) is available.
6. First aid equipment, fire extinguishers and emergency telephone numbers are in place.

8.5 PROCEDURE VARIATIONS

It is anticipated that occasions will arise where deviations from the issued procedure will be required because of unanticipated problems. This will be documented on a Procedure Variation Sheet, which will become a permanent part of the WTG documentation. The Procedure Variation Sheet is an integral part of each written procedure and is filled out whenever a deviation from the procedure is required or authorized.

8.6 ASSEMBLY SAFETY

The WTG Product and Safety Assurance Engineer will monitor the assembly operations and will be present during all operations. He will have the authority to stop any operation because of a hazardous condition. Operations may proceed when he is satisfied that the condition has been satisfactorily corrected.

8.7 TRAINING

Because of the complexity or potentially hazardous condition of some assembly operations, it may be necessary to provide training or orientation for personnel performing these operations. The Manager - MOD-5A Hardware Integration will determine which assembly operations require special training for personnel and will be responsible to insure such training is provided.

SECTION 9.0

SYSTEMS TEST

WTG Systems Test personnel will operate in close proximity to potentially hazardous conditions. Typical conditions which must be considered in the preparation of test procedures and safety precautions and restrictions are:

1. Rotating equipment in confined areas.
2. Personnel operating on elevated platforms.
3. Large static loads being imposed during mechanical loading of the system.
4. High electrical voltages.
5. High pressure hydraulic systems.
6. Movement and lifting of large, heavy equipment.
7. Movement of mechanisms in confined areas.

9.1 TEST PLANS AND PROCEDURES

All test operations will be performed to Standing Instructions (S.I.'s). Each S.I. is assigned a six digit number from a block of numbers assigned for S.I.'s. Standing instructions are controlled by Print Control in the same manner as drawings and specifications. Permanent changes to S.I.'s are made by Standing Instruction Revisions (S.I.R.'s) which are controlled in the same manner as drawing change notices. Non-permanent deviations from a procedure are documented on a Procedure Variation Sheet which is an integral part of each S.I. and is filled out whenever a deviation from a procedure is required or authorized. S.I.'s and S.I.R.'s require approval by the Managers of Design Engineering, Hardware Integration (Test) and the Product and Safety Assurance Engineer. Procedure Variation Sheets require approval by the Test Conductor and the Product and Safety Assurance Engineer. Copies of an S.I. cover sheet, an S.I.R. form and a PVS form are included in Appendix A of this plan.

Standing Instructions shall contain the following as a minimum:

1. Equipment and facilities required for test.
2. Precautions, limitations and requirements imposed for WTG equipment and personnel safety.
3. Operating parameters, required inputs to the system and expected outputs from the system.
4. Acceptance/rejection criteria.
5. Emergency Procedures.

9.2 TEST ANOMALIES AND FAILURES

All test anomalies and failures will be recorded on Defect Reports (DR's) and Nonconformance Reports (NR's) in accordance with the WTG Product Assurance Plan (Document No. 47A380018). The disposition of the DR or NR documents the specific actions required to correct the deficiency noted. Copies of the DR and NR forms are included in Appendix A of this plan.

9.3 TEST SAFETY REVIEW

Prior to the initiation of any test operations, a Test Safety Review will be performed by the MOD-5A Safety Review Board. This review will verify as a minimum:

1. The test procedure has been prepared, approved and issued.
2. All personnel associated with the testing are familiar with the procedures, hazards, special precautions and are competent in their assigned tasks.
3. All preliminary assembly operations and subassembly inspections and tests have been completed satisfactorily.
4. All test equipment, tooling and fixtures are available and have been verified to satisfy documented requirements.
5. All safety and security devices, signs and procedures are implemented and operational.
6. Personnel access lists have been prepared and are posted.

9.4 TEST LOG BOOK

A log book will be maintained during all test operations. This log book will be continuously maintained by the Test Conductor. This log book will include records of the following:

1. Significant events - anomalies, failures, trouble-shooting, changes to equipment.
2. Changes in personnel.
3. Safety briefings and violations.

9.5 TEST SAFETY

The WTG Product and Safety Assurance Engineer will monitor testing operations and will be present during all operations. He shall have the authority to stop any operation because of a hazardous condition. Operations may proceed when he is satisfied that the condition has been eliminated.

9.6 TRAINING

Prior to initiation of any testing, all operations will be reviewed for the need for any special safety training. When required, this training will take place prior to initiation of testing. The Manager, WTG Hardware Integration is responsible for identifying operations requiring special training for personnel and to provide the necessary training on a timely basis.

SECTION 10.0

SITE PREPARATION AND TOWER ERECTION

Site preparation and tower erection will be performed by subcontractors under direction of the General Electric Advanced Energy Programs Department. The subcontractors' safety procedures shall be used for this phase of the field operation.

The GE-AEPD Site Manager will review the subcontractors' safety procedures to assure:

1. Procedures meet all local, state and federal requirements.
2. Adequate provisions are included to preclude damage to WTG equipment.
3. Subcontractors have assigned individuals responsible for personnel and equipment safety.

The GE-AEPD Site Manager shall maintain responsibility for program safety and shall provide an audit function during the site preparation phase.

Prior to use, equipment such as the lift, work platforms and access ladders shall be checked for safe operation, evidence of proof loading, adequate safety railings and other protective devices. Certification or licensing, where required by state laws, shall be obtained by the supplier or subcontractor and will be verified by the GE-AEPD Site Manager.

SECTION 11.0

WTG ASSEMBLY AND ERECTION

11.1 TRANSPORTATION

The WTG equipment shall be shipped by conventional transportation, rail or truck, in several large, heavy modules. During the shipment phase, GE-AEPD will monitor critical shipment operations, with particular emphasis on transfer of equipment from truck to rail and the reverse. Emphasis will be placed on:

1. Adequacy of transportation equipment and fixtures.
2. Adequacy of protective equipment.
    a) Skids and packaging
    b) Tie downs
    c) Protection against weather
3. Adequacy of cranes, slings, cables and other transfer equipment.
4. Capability and training of personnel performing transfer and transportation operations.

11.2 INSPECTION AND CHECKOUT

On receipt at the erection site, the WTG equipment will be inspected for transportation damage and completeness of shipment. The inspection shall include, where possible, checkout of the equipment to assure maintenance of alignments and freedom of moving parts prior to erection. These operations will be performed to written planning prepared by Product Assurance. The P.A. representative at the site will be responsible for performing these inspections. In the event there is no P.A. representative at the site, the GE-AEPD Site Manager is responsible to insure these inspections are performed.

11.3 SAFETY REVIEW

Prior to erection of the total WTG and/or the individual modules (nacelle, hub, blades), a Safety Review will be performed by a special Review Board composed of the following:

1. GE Site Manager.
2. Construction Subcontractor Site Manager.
3. WTG Assembly & Test Operations Representative.
4. WTG Product and Safety Assurance Engineer.

This review will ascertain:

1. Lifting equipment is available and verified to satisfy applicable requirements.
2. All procedures to be implemented are in place and have had the appropriate reviews and approvals.
3. Preceding equipment inspections and checkouts have been satisfactorily completed.
4. Required personnel are available and have been adequately trained, and personnel safety equipment (hardhats, safety glasses, shoes, safety belts and lines) is available and in good condition.
5. All required tools and fixtures are available and have been accepted by Product Assurance as conforming to design documentation.

6. Atmospheric conditions are suitable for the required lifts, including a maximum allowable wind for lifting conditions.

11.4 SITE SAFETY

The WTG erection shall be continuously monitored for personnel and equipment safety. The GE Site Manager shall be responsible for monitoring safety during the erection operation and shall have authority to discontinue any operation that he considers hazardous to personnel or WTG equipment. An operation discontinued for safety reasons can be resumed when the GE Site Manager is assured the hazardous condition has been corrected. The GE Site Manager may delegate this responsibility to the WTG Assembly and Test Operations Representative at his discretion.

SECTION 12.0

WTG OPERATIONAL CHECKOUT AND TEST

12.1 SAFETY CONSIDERATIONS

The WTG shall be checked out, started and acceptance tested to written procedures following erection. Included in these procedures will be the safety regulations and precautions required for safely testing the fully assembled WTG. Included in these safety requirements will be:

1. Personnel access during various test and weather conditions.
    - a) No personnel in nacelle or yaw structure when the rotor is turning.
    - b) Access limitations due to weather, maximum allowable wind speed, etc.
2. Personnel limitations and safety equipment required when on nacelle, yaw structure or tower.
3. Conditions required for test:
    - a) Weather conditions
    - b) Equipment status
4. Emergency procedures:
    - a) Nacelle, yaw structure and tower evacuation
    - b) Equipment failures or malfunctions
    - c) Adverse weather
5. Safety and emergency equipment required:
    - a) Harnesses, lifelines, platforms, hats, glasses, shoes

   b) Fire extinguishers
   c) First-aid equipment

6. Emergency telephone numbers:
   a) Fire
   b) Ambulance
   c) Police
   d) Utility

12.2 PROCEDURES

Test procedures will be Standing Instructions and will be issued and controlled as specified in Paragraph 9.1 of this plan.

12.3 PROCEDURE CHANGES

Changes to Standing Instructions will be issued and controlled as specified in Paragraph 9.1 of this plan. For purposes of expediency, however, all changes at the field site may be initially documented on the PVS sheet of the S.I., but all changes of a permanent nature must be followed up with a formal change to the S.I. with an S.I.R. The Manager, MOD-5A Design Engineering will determine which variations are of a permanent nature and, therefore, require issuance of an S.I.R.

12.4 TEST ANOMALIES AND FAILURES

All test anomalies and failures will be recorded on DR's and NR's in accordance with the WTG Product Assurance Program Plan (Document No. 47A380018).

12.5 OPERATIONAL TEST SAFETY REVIEW

Prior to any operational testing of the WTG, an Operational Safety Review will be performed by the Site Review Board of Paragraph 11.3. The purpose of the review is to ascertain:

1. All previous erection, assembly and checkout operations have been completed satisfactorily.
2. Procedures are available and test personnel have been trained in their use.
3. Test personnel have been trained in emergency procedures and are knowledgeable of safety controls and equipment.
4. Equipment and tools are available and have been properly inspected, accepted and calibrated as required.
5. Safety and emergency equipment are available and have been found to be complete and acceptable.
6. Warning notices, signs and emergency numbers are prominently displayed.

Upon completion of the review, documentation regarding minutes of the meeting, action items and action item closeouts will be prepared and made part of MOD-5A permanent records.

12.6 TEST LOG BOOK

A log book will be maintained during all operations. This log book will be continuously maintained by the Site Manager or his delegate. This log book will include records of the following:

1. Significant events - anomalies, failures, trouble-shooting, changes to equipment (WTG and test).
2. Changes in personnel.
3. Safety briefings and violations.

12.7 OPERATIONAL CHECKOUT AND TEST SAFETY

The WTG Product and Safety Assurance Engineer will monitor testing operations and will be present during any potentially hazardous operation. He shall have the authority to stop any operations because of a hazardous condition. Operations may proceed when he is satisfied that the condition has been eliminated.

12.8 TRAINING

Prior to initiation of any testing, all operations will be reviewed for the need for any special training. When required, this training will take place prior to initiation of testing and will be a Safety Review requirement.

SECTION 13.0

UTILITY TRAINING AND OPERATION

13.1 PURPOSE

Utility training will be a two-phase operation to assure total familiarity with the WTG system and its operation.

13.2 UTILITY TRAINING PLAN

Utility training will be conducted in accordance with the Operations and Maintenance Manuals. This training will insure that utility personnel are knowledgeable in all phases of WTG operation including:

1. Safety features incorporated into the design.
2. Emergency procedures.
3. Personnel safety features and procedures.
4. Maintenance Procedures.

13.3 UTILITY OPERATIONS AND MAINTENANCE MANUALS

Utility Operations Manuals and Maintenance Manuals will be prepared for use by the operating utility. In addition to operational information, these manuals will contain:

1. Maintenance and inspection requirements and procedures.

2. Emergency procedures.

3. Equipment and personnel safety features and procedures.

SECTION 14.0

SAFETY REPORTS AND DOCUMENTATION

14.1 ACCIDENT REPORTING (SPACE DIVISION)

All accidents will be reported in accordance with Section A-4.0 of the Valley Forge Space Center Safety Manual. A copy of this instruction is included in Appendix A of this plan.

14.2 ACCIDENT REPORTING (NASA-LeRC)

All accidents or incidents (mishaps) will be reported to the General Electric WTG Program Manager immediately. He, in turn, will immediately notify the NASA-LeRC Project Manager and Contracting Officer of any accident resulting in a fatality, disabling injury or property damage of $10,000 or more. He will take immediate steps to initiate investigations and analyses to determine the cause and the corrective actions proposed or taken. He shall forward two full reports to the NASA-LeRC Contracting Officer.

Accidents/incidents of a non-severe level will be subject to appraisal by the General Electric WTG Product and Safety Assurance Engineer. He will take the necessary steps to effect a remedy for the mishap and corrective action to avoid repetition. These will be documented and a copy forwarded to the NASA-LeRc Contracting Officer. Specific safety hazards and significant safety matters will be included in the monthly status reports as appropriate.

APPENDIX A

GENERAL ELECTRIC

ADVANCED ENERGY PROGRAMS DEPARTMENT

SI NO. __________

CONTRACT NO. __________

TITLE:

	REVISIONS		
LTR	DESCRIPTION	DATE	BY

TABLE OF CONTENTS

APPROVALS:

PROGRAM OFFICE __________ DATE __________

ENGINEERING __________ DATE __________

SAFETY __________ DATE __________

QUALITY CONTROL __________ DATE __________

GENERAL ELECTRIC

ADVANCED ENERGY PROGRAMS DEPARTMENT

STANDING INSTRUCTION REVISION

Security Classification	S.I.R. No.	S.I.R. Issue Date
Drawing No.	Component Name	Program Class

GENERAL ELECTRIC

ADVANCED ENERGY PROGRAMS DEPARTMENT

SI NO.________

PAGE____ OF____

PROCEDURE VARIATION SHEET

ITEM NO.	REFERENCE PARAGRAPH	VARIATION DESCRIPTION	GE TC	GE QC	GOV. QC		SIR NO.	ACTION REQUIRED

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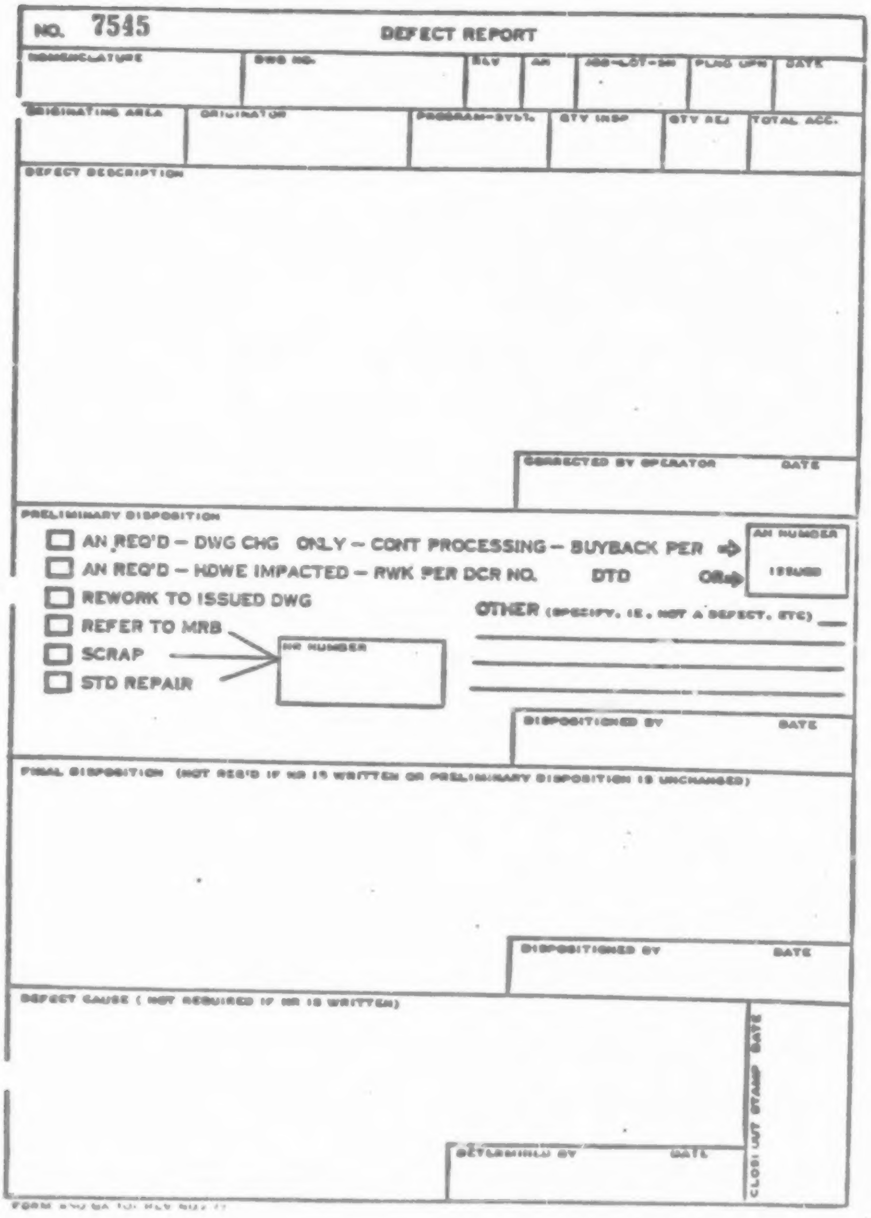

NO. 7545 **DEFECT REPORT**

NOMENCLATURE	DWG NO.	REV	AN	JOB-LOT-SN	PLNG UPN	DATE

ORIGINATING AREA	ORIGINATOR	PROGRAM-SYST.	QTY INSP	QTY REJ	TOTAL ACC.

DEFECT DESCRIPTION

CORRECTED BY OPERATOR DATE

PRELIMINARY DISPOSITION

☐ AN REQ'D – DWG CHG ONLY – CONT PROCESSING – BUYBACK PER ⇨ AN NUMBER
☐ AN REQ'D – HDWE IMPACTED – RWK PER DCR NO. DTD OR⇨ ISSUED
☐ REWORK TO ISSUED DWG
☐ REFER TO MRB
☐ SCRAP
☐ STD REPAIR

MR NUMBER

OTHER (SPECIFY, IE., NOT A DEFECT, ETC) ____

DISPOSITIONED BY DATE

FINAL DISPOSITION (NOT REQ'D IF MR IS WRITTEN OR PRELIMINARY DISPOSITION IS UNCHANGED)

DISPOSITIONED BY DATE

DEFECT CAUSE (NOT REQUIRED IF MR IS WRITTEN)

DETERMINED BY DATE

CLOSE OUT STAMP DATE

FORM [illegible]

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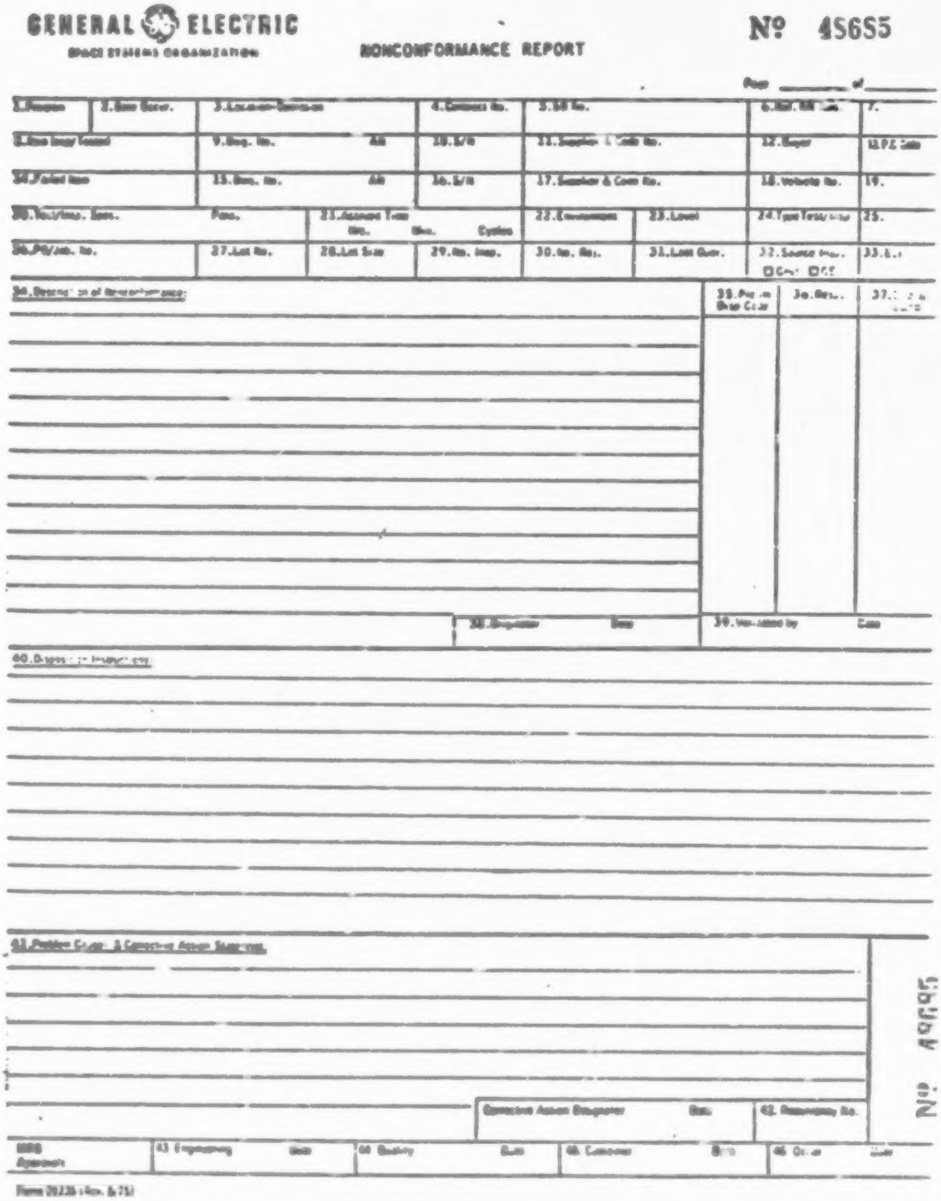

GENERAL ELECTRIC
SPACE SYSTEMS ORGANIZATION

NONCONFORMANCE REPORT

Nº 45655

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Valley Forge Space Center Safety Manual

SUBJECT	CLASSIFICATION	ISSUED	NUMBER
ACCIDENT REPORTING	ADMINISTRATIVE PROCEDURE	MARCH 1981	A-4.0

4.1 PURPOSE

This instruction outlines the responsibilities, procedures, and basic information on accident reporting.

4.2 PERSONNEL INJURY REPORTING

If you are injured, no matter how slight the injury, report it to your supervisor and then go to the dispensary. (In case of emergency, go directly to the dispensary.) If not treated, a neglected cut, bruise, burn, or scratch may become infected. Accident form FF-40C is requested for injuries of a serious nature or that have a serious potential. This form should be filled out by the injured's immediate supervisor and, as it can and should serve as both an investigative and preventive tool, is best completed with the injured person present.

4.3 VEHICLE ACCIDENT REPORTING

Any accident involving a company vehicle must be filed on accident report ML-2 with the Accountant, Taxes and Insurance, and a copy for the Industrial Safety and Hygiene Office.

4.4 ACCIDENT/INCIDENT REPORTING

Accidents involving property damage, injury to personnel or an incident with loss or injury potential, shall be verbally reported immediately to the Industrial Safety and Hygiene Office. The following Accident/Incident classes are defined for formal reporting purposes:

Class I	Catastrophe - Any event with loss or damage in excess of $50,000 or results in one or more fatalities or hospitalization of five or more employees.
Class II	Major - Any event with loss or damage in excess of $5,000 or results in disabling injury or hospitalization of more than one employee.
Class III	Significant - Any event with loss or damage in excess of $100 or that requires medical treatment (other than First Aid) to any employee.
Class IV	Minor - Any event which results in a loss or damage to property or injury to personnel and not qualifying for other classes.

INTERPRETATION CONTACT		
SAFETY ENGINEER	NOVEMBER 1980	A-4-1

C-6

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Class I or II Accident/Incident will be reported as follows:

Supervisor in the accident area	Terminates all activity associated with the accident. Immediately reports the accident/incident by dialing A-FIRE (2-3173) and then his manager.
Patrol Communications Center	Upon receipt of a report of a Class I or II accident, activates emergency system to alert appropriate emergency stations, notifies Manager, Security and Distribution Services.
Manager, Industrial Safety and Hygiene	Notifies Manager, Industrial Security, Safety, Medical and Administrative Services and initiates Plant Fire and Safety Protection activity as attention demands.
Manager, Industrial Security, Safety, Medical and Administrative Services	Notifies the following and directs initial investigative action: Division Vice President Appropriate General Manager Mgr. Relations, Organization and Manpower Operation GE Liaison with AFPRO Legal Counsel (as required) Division Public Relations (as required)

Class III Accident/Incident shall be reported as follows:

Supervisor in the accident area	Takes necessary steps to prevent additional injury or damage. Notifies the Industrial Safety and Hygiene Office (2-4570) as soon as possible, and his manager.
Industrial Safety and Hygiene Office	Notifies the Manager Industrial Safety and Hygiene. Implements regular accident procedure and, in injury cases, coordinates accident procedures with Medical Services.
Manager, Industrial Safety and Hygiene	Notifies the Manager Industrial Security, Safety, Medical and Administrative Services. Directs and coordinates accident investigation and corrective action activity.
Manager, Industrial Security, Safety, Medical and Administrative Services	Directs overall accident/incident investigation, reporting and correction actions. Submits final accident/incident report according to requirements of authorized private and government agencies.

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Class IV Accident/Injury

Supervisor in the accident area	Notifies the Industrial Safety and Hygiene Office within 24 hours of the incident and notifies his Manager.
Industrial Safety and Hygiene	Reviews accident report, investigates situation as dictated by scope of the problem and maintains records for reference when needed.

4.5 WORKERS' COMPENSATION INFORMATION

The following information applies if you are injured as a result of an accident, or in the course of your employment, or if you are suffering a disability due to an occupational disease.

1. In Pennsylvania, unless you or someone in your behalf, or some of your dependents or someone in their behalf, shall give notice to the employer within 21 days after the accident, no Workers' Compensation shall be due until notice is given. Unless notice is given to the employer within 120 days after the accident, no compensation shall be allowed.

   In cases of personal injury all claims for compensation shall be forever barred, unless a petition is filed with the Workers' Compensation Bureau within two years from the data of accident or date of death.

   Under the Pennsylvania law, if your employer will not accept your claim or enter into an agreement to pay compensation, then you should file a petition with the Bureau of Occupational Injury and Disease, Department of Labor and Industry, Labor and Industry Building, Harrisburg, Pennsylvania. This Bureau will furnish petition forms or any other information you desire concerning your rights.

2. Occupational disease contracted in the course of your employment should be reported to your employer immediately.

   In Pennsylvania, unless you or someone in your behalf, or some of your dependents or someone in their behalf, shall give notice of disability to the employer liable for compensation within 21 days after compensable disability begins, no compensation shall be due until such notice is given. Unless such notice is given to the employer within 120 days after the beginning of compensable disability, no compensation shall be allowed.

   In cases of disability due to an occupational disease, all claims for compensation shall be forever barred, unless a petition is filed within two years after compensable disability begins.

   For additional information concerning your benefits or for any other information about Workers' Compensation or occupational disease, write:

   Bureau of Occupational Injury and Disease
   Labor and Industry Building
   Harrisburg, Pennsylvania 17120.

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APPENDIX D
GE - MOD-5A CONFIGURATION MANAGEMENT PLAN

1.0 CONFIGURATION CONTROL PLAN

1.1 INTRODUCTION

Purpose - This plan defines the scope, objectives, responsibilities, and approach for Configuration Management within General Electric for the MOD-5A Wind Turbine Generator Program.

Scope - Configuration Management requirements set forth in this plan will be applicable to all equipment for the WTG Program.

Objectives - The objectives of the Configuration Management system are to:

(a) Provide documents supplying Configuration Identification that conform to Configuration Management practices for format and content.

(b) Coordinate and approve all Engineering Changes prior to incorporation into documents and hardware.

(c) Provide an accurate Configuration Identification of hardware at any point in time.

(d) Provide a uniform means of reporting Configuration Management data.

1.2 DEFINITIONS

Configuration - The functional and/or physical characteristics of hardware/software as set forth in Configuration Identification and achieved in a product.

Configuration Management - A discipline for applying technical and administrative direction and surveillance to identify record control documentation and changes thereto.

Configuration Control - The systematic evaluation, coordination and implementation of Engineering Changes.

Configuration Identification - The current approved engineering definition of an End Item as set forth in the specification and drawings.

Configuration Accounting - The recording and reporting of the information that is needed to manage Configuration effectively, including a listing of the approved Configuration Identification, the status of proposed Engineering Changes to Configuration and the implementation status of approved Engineering Changes.

End Item (EI) - An aggregation of hardware/software or any of its discrete portions which satisfies an end use function.

Engineering Change - An alteration in the Configuration of an End Item.

1.3 RESPONSIBILITIES

The procedures and practices for Configuration Management to be applied to the WTG Program are as defined below. The Program Manager approves or delegates approval within his Program Office of all Configuration Identification before its issue for use on the Program. He or his delegate approve or disapprove all Engineering Changes proposed to the Configuration Identification. The Functional Managers (Engineering, Manufacturing and Product Assurance) are responsible for the portion of Configuration Management performed within their respective Functional area: Engineering for Configuration Identification, Accounting and Control; Product Assurance for Configuration Verification; and Manufacturing for hardware conformance and control and supporting the other functions as applicable.

1.4 APPROACH

Configuration Management will be applied to those specific End Items delineated in the Statement of Work for the WTG Program. A system specification will be issued and maintained to establish the requirements of all End Items of deliverable equipment. An End Item specification will be issued and maintained to establish the requirements for each End Item. A top assembly drawing will be issued and maintained to establish the requirements for each End Item. The suffix number established on the top assembly drawing, which is combined with the drawing number to provide the End Item identification number, will be changed when:

(a) a change is made to a part to be used in the assembly and the part is not interchangeable with parts used in previous assemblies; or

(b) a change is made that would affect the performance, durability or interchangeability of the End Item.

The identification number of an End Item will not be changed to reflect the introduction of interchangeable changes which occur in the normal production of equipment; this information will be available from Assembly Breakdown lists and logbooks. When necessary, to maintain clarity of engineering definition, a new drawing may be issued to establish a new End Item identification number. Subcontractors will meet the Configuration Management objective of this plan through requirements established in GE procurement documents.

All Engineering Changes will be defined on Engineering Change Notices which will be assigned appropriate classification in accordance with Section 12.2.3.9. Engineering Changes with a classification of "Class 1" will be submitted to NASA for approval prior to implementation, following design freeze.

1.5 CONFIGURATION IDENTIFICATION

(a) Documentation format and content will follow standard GE/AEPD format for drawings and specifications.

(b) Document approval requirements are established in GE Operation Instructions. Specifications which require customer review and approval will be specified in the contract work statement. After approval, the documents will be issued and placed under the control of the Configuration Control Office, except those with an "SK" prefix. Documents with the "SK" prefix are under the control of the responsible Design Engineer; they are used for engineering development purposes only.

(c) All issued documents, except those with an "SK" prefix, will be controlled by the Configuration Control Office, which maintains records of the issue and revision of each document. After issue, the original document will be "Signed-out" to the responsible function for revision purposes only. Copies of documents will be distributed after issue or revision to individuals who have been established as having a need for the information by the Program Manager.

(d) Document Identification numbers used on specifications and drawings will be taken from blocks of numbers assigned to the Program from the General Electric Space Division. The numbers will be administered by the Configuration Control Office to insure no duplication in assignment. Item identification numbers used on hardware will consist of the assigned drawing number and a suffix.

Once an item identification number is established on a drawing, the Configuration of the item, as defined on the drawing, can not be changed without changing the item identification number except when the following criteria are met:

(1) The Configuration for a part may be changed as long as the change is identifiable by visual inspection and all parts are made or reworked to the latest configuration identification.

(2) The Configuration for an assembly may be changed as long as all assemblies will meet the following criteria and disassembly or rework of assembled items is not required:

(a) Performance or durability is not affected to an extent that superseded assemblies must be discarded.

(b) Interchangeability of superseded and superseding parts in the assembly is not affected.

(c) Interchangeability of superseded and superseding assemblies in their next higher assembly is not affected.

(3) The configuration for a material, process or standard part may be changed as long as the change will not adversely affect the interchangeability, performance or durability of parts or assemblies using the material, process or standard part.

1.6 CONFIGURATION CONTROL

(a) Engineering Change Notices (ECN) will be written to describe all Engineering Changes, establish the introduction point of the change in hardware and authorize disposition of existing material affected by the change, except engineering changes to documents with an "SK" prefix. Engineering Changes to documents with the "SK" prefix and the hardware made to them are the responsibility of the responsible Design Engineer. Each ECN will contain information on the nature and reason for the change in sufficient detail to support the review of the ECN. All ECN's will be reviewed and approved or rejected by a Configuration Control Board (CCB) established for the Program. All rejected ECN's will be returned to the initiator with reasons for rejection. Approved ECN's that are designated Class 1 will be submitted to NASA as Program Change Proposals for review and approval. The Class 1 ECN's, after approval by NASA, and all approved Class 2 ECN's will be distributed to the affected Functions for use in incorporating the Engineering Change in the affected documents and/or hardware.

(b) A Configuration Control Board will be established for the Program to approve or reject proposed Engineering changes submitted on ECN's. The CCB will consist of representatives of: (1) WTG Engineering, (2) Production Control, (3) Quality Control, (4) Program Office, and (5) a Chairman reporting to the Manager - WTG Project Engineering. Each CCB Representative ensures that each ECN is acceptable to his Function and that his Function will be able to accomplish the Engineering Change as agreed to on the ECN. The CCB Chairman ensures the efficient functioning of the CCB, that each ECN is fully integrated and that Configuration Identification requirements are not violated by an approved Engineering Change. The quantity and frequency of ECN submissions to the CCB Chairman will be used to determine the operation of the CCB.

The CCB Chairman is required to provide timely notification to the NASA Program Office of all Class 1 changes.

(c) The disciplines of Configuration Management will be imposed in all Subcontractors Work Statements. After a subcontractor design is approved by GE, he will be required to submit Design Change Requests (DCR) to GE for approval before initiating Engineering Change in documents or hardware. The processing of the DCR within GE will be administered by the Chairman of the CCB to ensure that GE Configuration Identification is maintained. The CCB will review all DCR's for approval or rejection.

1.7 CONFIGURATION ACCOUNTING

(a) A list will be prepared, maintained and distributed by the Configuration Control Office to define the Configuration Identification for each End Item. The list will identify all item identification numbers to be used in an End Item. When an interchangeable Engineering Change is introduced in an End Item, the identification numbers of the superseded and superseding items will be shown and identified to the serial number of the End Item on which the Engineering Change was introduced. The document status of each drawing which defines an item will be shown. The document status is the revision symbol, last incorporated ECN, and highest unincorporated ECN.

(b) A subcontractor's Design Change Request status sheet will be prepared, maintained and distributed by the Configuration Control Office. Each DCR in process within GE will be accounted for until approved or disapproved and returned to the Subcontractor.

(c) A list of documents and their effective issue date will be prepared, maintained and distributed by the Configuration Control Office.

1.8 CONFIGURATION VERIFICATION

Verification will be accomplished by the Quality Control Function by comparisons of hardware with the applicable engineering documents. The details of configuration verification are covered in the Quality Assurance Plan.

1.9 CHANGE CLASSES

Class 1 Engineering Changes are defined as affecting one or more of the following factors:

a Qualification status

b Significant effect on the relevancy of the reliability (and) technical data base of the program

c Performance outside specified tolerances d Weight, balance, moment of inertia outside specified tolerance

e Reliability, safety, maintainability or survivability

f Interface characteristics

g Electromagnetic characteristics

h Compatibility with support equipment

i Configuration to the extent that retrofit action would need to be taken

j Special process: those processes where uniform, high quality cannot be assured by inspection of articles alone. The contractor shall maintain an up-to-date listing of such processes.

Class 2 Changes -- All other changes are considered to be Class 2 changes. The class shall be documented on the Engineering Change Notice including justification of change classification.

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APPENDIX E
GE - MOD-5A DEFECT REPORTS FOR DEVELOPMENT HARDWARE

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INSPECTION REPORT

IR NO. 84010

PART NO. 47D382343 PT.5	ORDER NO. 7511-L2-[illegible] [illegible]	RECEIVING REPORT NO.	-
PART NAME SLEEVE - OUTER		REQUISITION NO.	-
SERIAL NO. 01 THRU 014	VENDOR GENERAL ELECTRIC CO. AEPD	ENGINEER	-
QUANTITY 14 PCS.	ADDRESS EVENDALE, OHIO.		

ITEM	B/P DIMENSION	ZONE	MEASURED	DISPOSITION CODE
A	$.650 \pm {.001 \atop .000}$ DIA.	-	(S/N 3) .652 FOR .08 DEEP (S/N 4) .6510 TO .6514 OUT OF ROUND &	
			TAPERED.	
~~B~~	~~.015 X 45°~~	-	(14 PCS.) ~~SHARP EDGE ON THIS CHAMFER.~~ REWORKED W/S.	
~~C~~	~~.250 DEEP~~	-	THREAD DEPTH IS SHORT – CHECKS .15-.20 ~~(14 PCS.)~~ REWORKED W.P.	

[illegible]

A. Chandler 2-24-84

DISPOSITION CODES
☐ 1. ACCEPT AS IS – NO REWORK REQUIRED.
☐ 2. ACCEPT AS IS – REWORK REQUIRED BUT COST ESTIMATED AT LESS THAN [illegible] MAN HOURS
☐ 3. ACCEPT AS IS NEGOTIATE COST
☐ 4. RETURN TO VENDOR FOR REWORK OR REPLACEMENT.

INSPECTOR — DATE 2-14-84

DISPOSITION AUTHORIZED BY N.K. Lat[illegible] 2-22-84 — DATE 2-14-84

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INSPECTION REPORT

SN No. 84013

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PART NAME TEETER CUP			REQUISITION NO. -
SERIAL NO. 1 THRU 13	VENDOR GENERAL ELECTRIC CO. AEPD		ENGINEER -
QUANTITY 13 PCS.	ADDRESS EVENDALE, OHIO		

ITEM	B/P DIMENSION	ZONE	MEASURED	DISPOSITION (USE CODE*)
A	4.40		CHECKS 4.4124 (S/N 9)	
B	.015 X 45° CHAM.		CHECKS .012 TO .022 13 PCS.	
C	CONDITION		BURRS	

Existing [illegible] will not
[illegible] function (Ham)
effect [illegible] [illegible] 2-24-84
A. Cheddar 2-24-84

*DISPOSITION CODES
☒ 1. ACCEPT AS IS - NO REWORK REQUIRED.
☐ 2. ACCEPT AS IS - REWORK REQUIRED BUT COST ESTIMATED AT LESS THAN 8 MAN HOURS
☐ 3. ACCEPT AS IS NEGOTIATE COST
☐ 4. RETURN TO VENDOR FOR REWORK OR REPLACEMENT.

INSPECTOR DATE 2-22-84

DISPOSITION AUTHORIZED BY DATE

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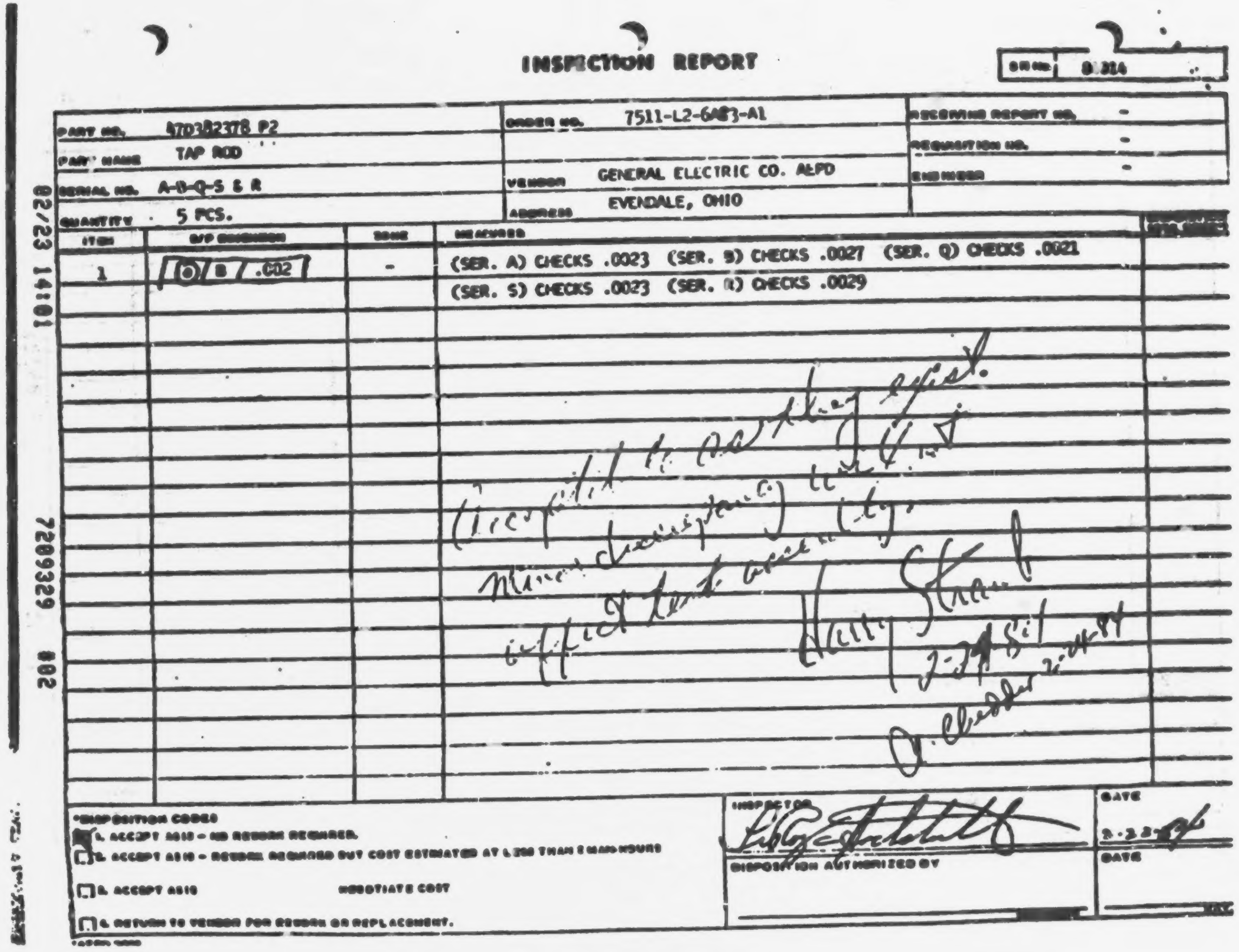

INSPECTION REPORT

SR NO.	B 314

PART NO.	470382378 P2	ORDER NO.	7511-L2-6A83-A1	RECEIVING REPORT NO.	-
PART NAME	TAP ROD			REQUISITION NO.	-
SERIAL NO.	A-B-Q-S & R	VENDOR	GENERAL ELECTRIC CO. AEPD	ENGINEER	-
QUANTITY	5 PCS.	ADDRESS	EVENDALE, OHIO		

ITEM	B/P DIMENSION	ZONE	MEASURED
1	⌭ B .002	-	(SER. A) CHECKS .0023 (SER. B) CHECKS .0027 (SER. Q) CHECKS .0021 (SER. S) CHECKS .0023 (SER. R) CHECKS .0029

Accepted to working agreement.
Minor discrepancy will not
affect test accuracy.
Harry Strand
2-24-84
O. Chadder 2-24-84

*DISPOSITION CODES
☒ 1. ACCEPT AS IS – NO REWORK REQUIRED.
☐ 2. ACCEPT AS IS – REWORK REQUIRED BUT COST ESTIMATED AT LESS THAN 2 MAN HOURS
☐ 3. ACCEPT AS IS NEGOTIATE COST
☐ 4. RETURN TO VENDOR FOR REWORK OR REPLACEMENT.

INSPECTOR: [illegible] DATE: 2-23-84
DISPOSITION AUTHORIZED BY DATE

02/23 14:01 7209329 002

INSPECTION REPORT

84015

PART NO.	47D382-343 P12	ORDER NO.	7511-L2-6A13-A2	RECEIVING REPORT NO.	-
PART NAME	"T" BLOCK			REQUISITION NO.	-
SERIAL NO.		VENDOR	GENERAL ELECTRIC CO. AEPD	ENGINEER	-
QUANTITY	1	ADDRESS	EVENDALE, OHIO		

ITEM	B/P DIMENSION	ZONE	MEASURED
1	~~5/8-18 x 1.25 DEEP~~		~~CHECKS 1.1788 - 1.1964 - 1.105 DEEP (4 PLACES)~~ Reworked [illegible] 3-1-84
2	$1.000 \begin{smallmatrix} +.001 \\ -.000 \end{smallmatrix}$ DIA.		CHECKS (TOP) 1.0018 (MIDDLE) 1.0008 (BOTTOM) 1.0012

[illegible]

[illegible] 3-9-84

Harry [illegible]

*DISPOSITION CODES

☑ 1. ACCEPT AS IS - NO REWORK REQUIRED.

☐ 2. ACCEPT AS IS - REWORK REQUIRED BUT COST ESTIMATED AT LESS THAN 2 MAN-HOURS

☐ 3. ACCEPT AS IS NEGOTIATE COST

☐ 4. RETURN TO VENDOR FOR REWORK OR REPLACEMENT.

AEPD [illegible]

INSPECTOR	DATE 2-22-84
DISPOSITION AUTHORIZED BY	DATE

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INSPECTION REPORT

SER NO. 84021

PART NO. 3

PART NAME SPHERICAL PLUG

SERIAL NO. 470382378

QUANTITY

ORDER NO. 7511-62-6A13-A1

VENDOR

ADDRESS

RECEIVING REPORT NO.

REQUISITION NO.

ENGINEER

ITEM	B/P DIMENSION	ZONE	MEASURED	DISPOSITION*
1	2.00 ±.020		CHECKS 1.960 on part 2A	
2	.60 ±.020		CHECKS .547 on part 2A	
3	.12 R		No Radius - CHECKS as a chamfer ✓	
4	2.85 ±.020		undercut .005 next to radius - not a good blend of radius & 2.85 dia.	
			2.850 DIA IS AT LOW LIMIT ✓	

Acceptable

*DISPOSITION CODES

☒ 1. ACCEPT AS IS - NO REWORK REQUIRED.

☐ 2. ACCEPT AS IS - REWORK REQUIRED BUT COST ESTIMATED AT LESS THAN 2 MAN-HOURS

☐ 3. ACCEPT AS IS NEGOTIATE COST

☐ 4. RETURN TO VENDOR FOR REWORK OR REPLACEMENT.

SPG 2000

INSPECTOR	DATE
Michael A Pierce	3-2-81
DISPOSITION AUTHORIZED BY	DATE

03/07 12:44 7209329 002

INSPECTION REPORT

DR NO. 84022

PART NO. 6	ORDER NO. 754-62-6A13-A2	RECEIVING REPORT NO.
PART NAME SHAFT PIN		REQUISITION NO.
DETAIL NO. 97D382343	VENDOR 4W	ENGINEER
QUANTITY 4	ADDRESS	

ITEM	B/P DIMENSION	ZONE	MEASURED	[illegible]
1	1.390 ±.001		CHECKS 1.386 on part #1	
2	" "		CHECKS 1.385 on part #2	
3	" "		CHECKS 1.395 on part #3	
4	" "		CHECKS 1.392 on part #4	
5	.460 ±.001		CHECKS .4575 on part #2	
6	.455 ±.001		CHECKS .452 on part #2	

OK accept as is
Harry 3-9-84

*DISPOSITION CODES

☑ 1. ACCEPT AS IS – NO REWORK REQUIRED.
☐ 2. ACCEPT AS IS – REWORK REQUIRED BUT COST ESTIMATED AT LESS THAN 2 MAN-HOURS
☐ 3. ACCEPT AS IS NEGOTIATE COST
☐ 4. RETURN TO VENDOR FOR REWORK OR REPLACEMENT.

STD 2000

INSPECTOR Michael O	DATE 3-2-84
DISPOSITION AUTHORIZED BY	DATE

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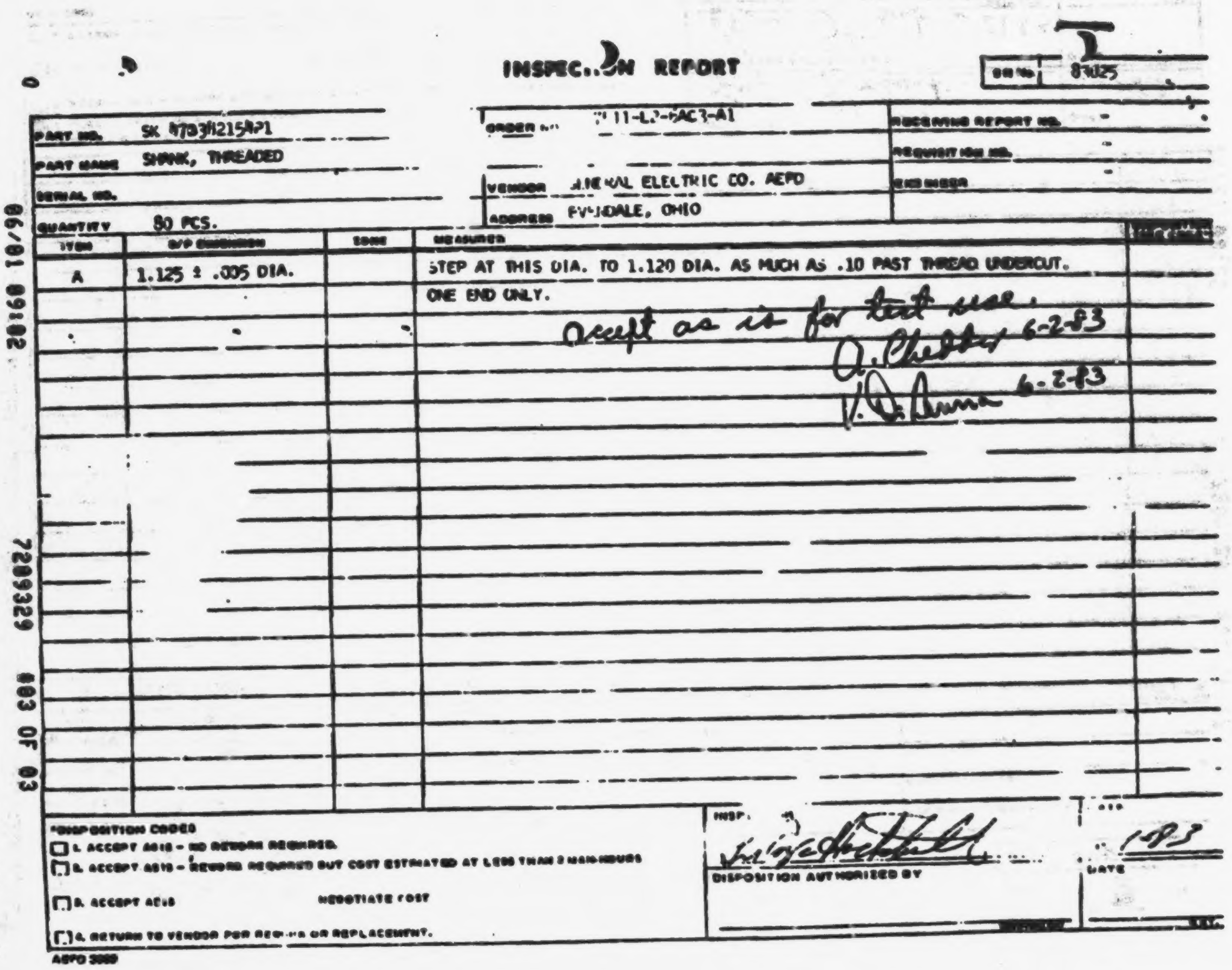

INSPECTION REPORT

DR No. 83025

PART NO.	SK 9703M215AP1	ORDER NO.	?11-L?-?AC3-A1
PART NAME	SHANK, THREADED	VENDOR	GENERAL ELECTRIC CO. AEPD
SERIAL NO.		ADDRESS	EVENDALE, OHIO
QUANTITY	80 PCS.		

RECEIVING REPORT NO. -
REQUISITION NO. -
ENGINEER -

ITEM	B/P DIMENSION	ZONE	MEASURED	[illegible]
A	1.125 ± .005 DIA.		STEP AT THIS DIA. TO 1.120 DIA. AS MUCH AS .10 PAST THREAD UNDERCUT.	
			ONE END ONLY.	
			Accept as is for test use.	
			A. [illegible] 6-2-83	
			[illegible] 6-2-83	

*DISPOSITION CODES
☐ 1. ACCEPT AS IS – NO REWORK REQUIRED.
☐ 2. ACCEPT AS IS – REWORK REQUIRED BUT COST ESTIMATED AT LESS THAN 2 MAN-HOURS
☐ 3. ACCEPT AS IS NEGOTIATE COST
☐ 4. RETURN TO VENDOR FOR REWORK OR REPLACEMENT.

INSP.
DISPOSITION AUTHORIZED BY
DATE 1983

AEPD 3000

06/01 09:02 7209329 003 OF 03

TO: Chedder x 2342
From E. Burns

INSPECTION REPORT

IR NO. 83032

PART NO. 47C382080 P1	ORDER NO. 7511-L2-6AC3-A1	RECEIVING REPORT NO.	-
PART NAME HOLLOW STUD.		REQUISITION NO.	-
SERIAL NO.	VENDOR GENERAL ELECTRIC CO. AEPD	ENGINEER	-
QUANTITY 11 PCS.	ADDRESS EVENDALE, OHIO		

ITEM	B/P DIMENSION	ZONE	MEASURED
A	1.140 $^{+.008}_{-.005}$	-	CHEKCS 1.149 - 1.152 (11 PCS.)

06/21 08:25 7209329 002 OF 02

DISPOSITION CODES

☒ 1. ACCEPT AS IS - NO REWORK REQUIRED.
☐ 2. ACCEPT AS IS - REWORK REQUIRED BUT COST ESTIMATED AT LESS THAN 2 MAN-HOURS
☐ 3. ACCEPT AS IS NEGOTIATE COST
☐ 4. RETURN TO VENDOR FOR REWORK OR REPLACEMENT.

AEPD 3000

INSPECTOR	DATE 6-17-83
DISPOSITION AUTHORIZED BY 6-21-83	DATE

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INSPECTION REPORT

[illegible] 8-3 83034

PART NO. SK 470382155
PART NAME FITTING END, LARGE STATIC TEST
SERIAL NO.
QUANTITY 3

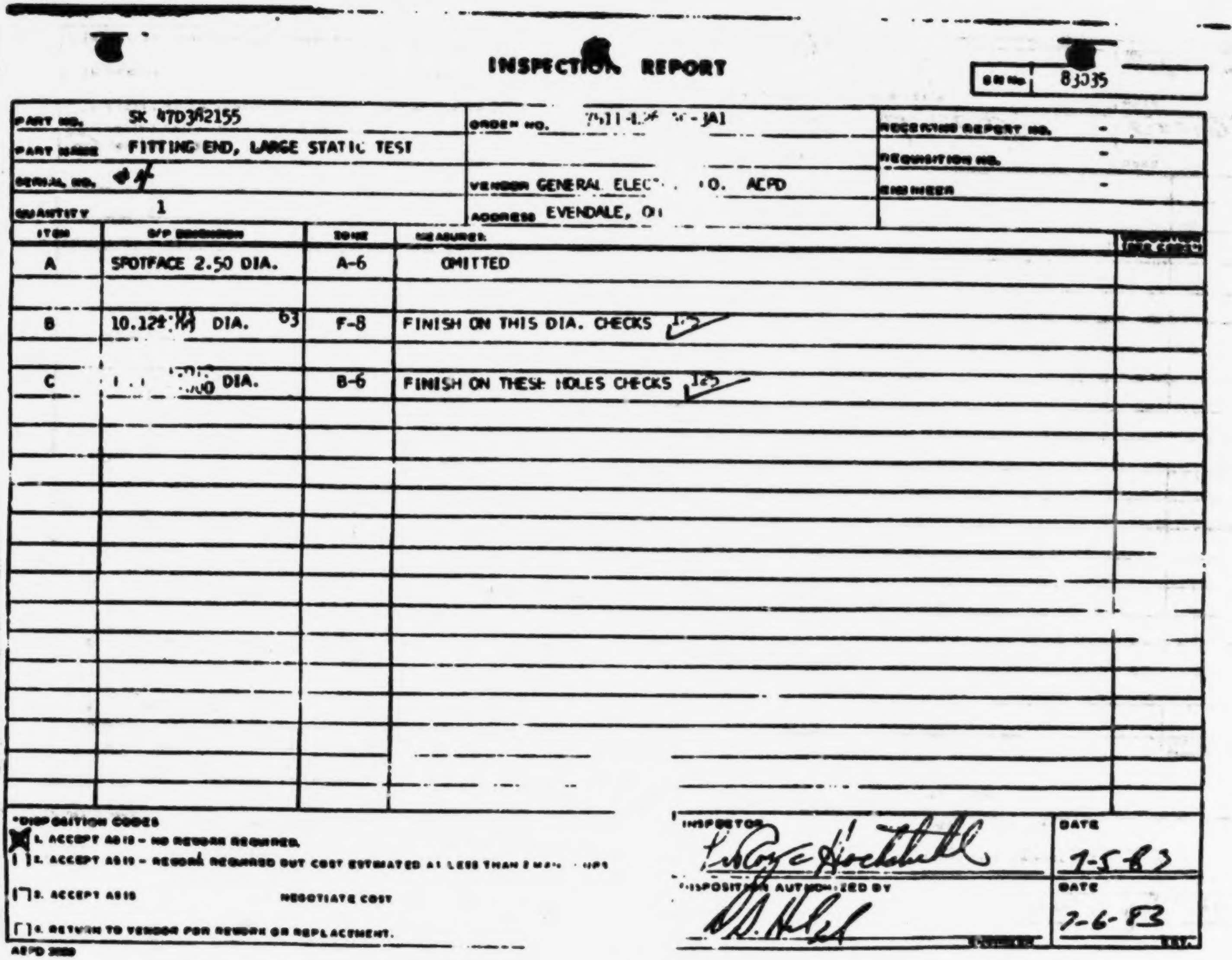
ORDER NO. [illegible]
VENDOR [illegible] ELECTRIC CO. AEPD
ADDRESS [illegible], OHIO

DISCREPANCY REPORT NO. -
REQUISITION NO. -
ENGINEER -

ITEM	B/P DIMENSION	ZONE	MEASURED	[illegible]
A	SPOTFACE 2.50 DIA.	A-6	OMITTED (3 PCS.)	
B	10.12 $^{+.03}_{-.00}$ DIA. 63	F-8	FINISH ON THIS DIA. CHECKS 125 (3 PCS.)	
C	1.218 $^{+.015}_{-.000}$ DIA.	B-6	FINISH ON THESE HOLES CHECKS 125 TO 250 (3 PCS.)	

*DISPOSITION CODES
☒ 1. ACCEPT AS IS - NO REWORK REQUIRED.
☐ 2. ACCEPT AS IS - REWORK REQUIRED BUT COST ESTIMATED AT LESS THAN 8 MAN HOURS
☐ 3. ACCEPT AS IS NEGOTIATE COST
☐ 4. RETURN TO VENDOR FOR REWORK OR REPLACEMENT.

INSPECTOR [illegible] DATE 6-23-83
DISPOSITION AUTHORIZED BY [illegible] DATE 6-24-83



INSPECTION REPORT

IR No. 83035

PART NO. SK 47D3R2155
PART NAME FITTING END, LARGE STATIC TEST
SERIAL NO. #4
QUANTITY 1

ORDER NO. 7511-1.2[illegible]-JA1
VENDOR GENERAL ELEC[illegible] CO. AEPD
ADDRESS EVENDALE, OH

RECEIVING REPORT NO. -
REQUISITION NO. -
ENGINEER -

ITEM	B/P DIMENSION	ZONE	MEASURED	DISPOSITION
A	SPOTFACE 2.50 DIA.	A-6	OMITTED	
B	10.12[illegible] DIA. 63	F-8	FINISH ON THIS DIA. CHECKS 125 ✓	
C	[illegible] DIA.	B-6	FINISH ON THESE HOLES CHECKS 125 ✓	

*DISPOSITION CODES
☒ 1. ACCEPT AS IS – NO REWORK REQUIRED.
☐ 2. ACCEPT AS IS – REWORK REQUIRED BUT COST ESTIMATED AT LESS THAN 2 MAN HOURS
☐ 3. ACCEPT AS IS NEGOTIATE COST
☐ 4. RETURN TO VENDOR FOR REWORK OR REPLACEMENT.
AEPD 2020

INSPECTOR
DATE 7-5-83

DISPOSITION AUTHORIZED BY
DATE 7-6-83

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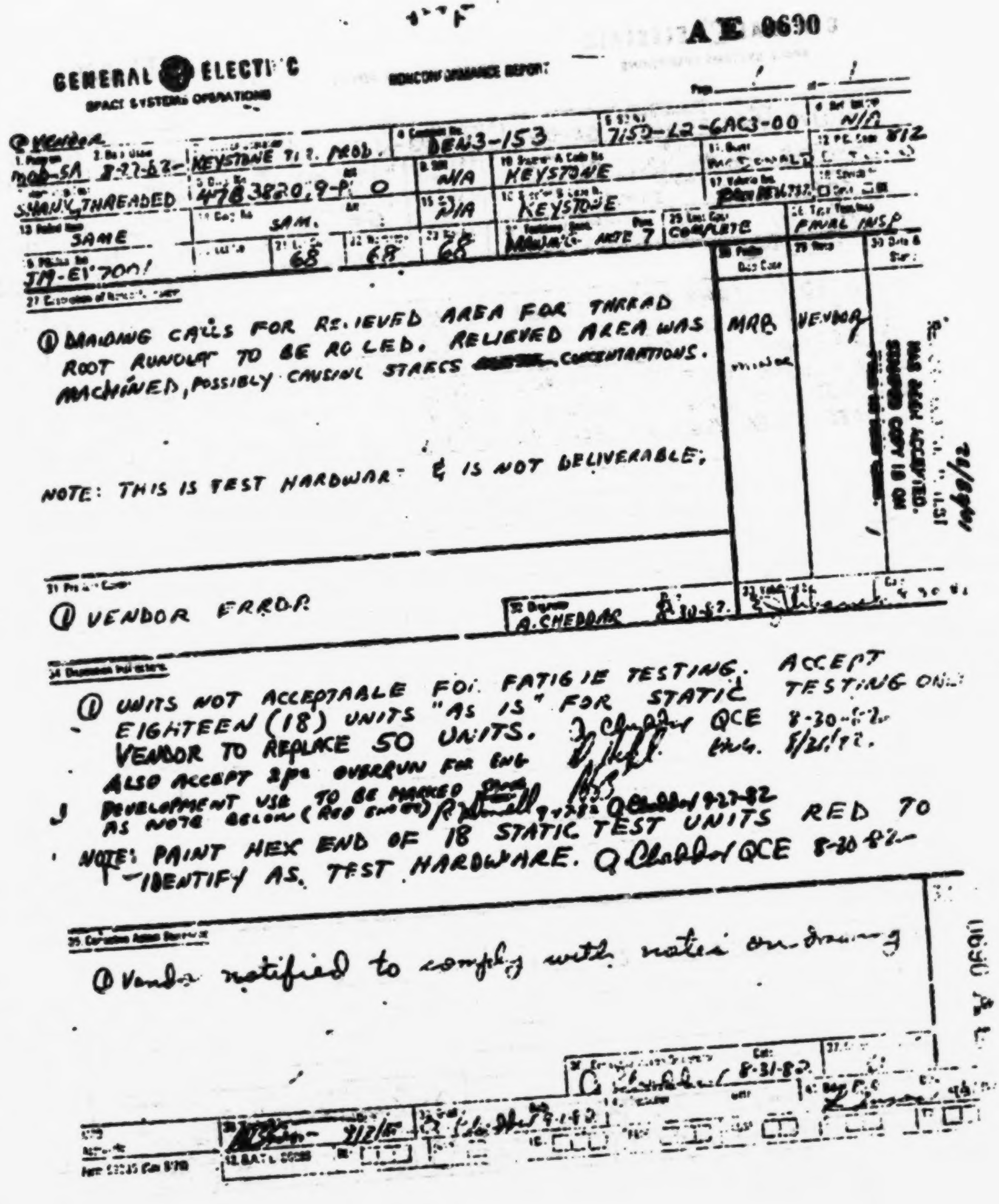

A E 0690

GENERAL ELECTRIC
SPACE SYSTEMS OPERATIONS

NONCONFORMANCE REPORT

Page 1 of 1

Vendor
MOD-SA 8-27-82
KEYSTONE T. R. PROD.
DEN3-153
7150-L2-6AC3-00
N/A
812
SHANK, THREADED
478 3820, 9-P 0
N/A
KEYSTONE
MCDONALD
N/A
KEYSTONE
SAME
SAM.
MANUFAC. NOTE 7
COMPLETE
FINAL INSP
JM-E1 7001
68
68
68

① DRAWING CALLS FOR RELIEVED AREA FOR THREAD ROOT RUNOUT TO BE ROLLED. RELIEVED AREA WAS MACHINED, POSSIBLY CAUSING STRESS ~~[illegible]~~ CONCENTRATIONS.

MRB
VENDOR
MINOR

NOTE: THIS IS TEST HARDWARE & IS NOT DELIVERABLE.

① VENDOR ERROR

A. CHEDDAR 8-30-82.

① UNITS NOT ACCEPTABLE FOR FATIGUE TESTING. ACCEPT EIGHTEEN (18) UNITS "AS IS" FOR STATIC TESTING ONLY. VENDOR TO REPLACE 50 UNITS. QCE 8-30-82. ENG. 8/30/82.
ALSO ACCEPT 2 pc OVERRUN FOR ENG DEVELOPMENT USE TO BE MARKED AS NOTE BELOW (RED ENDS) 9-27-82 9-27-82
NOTE: PAINT HEX END OF 18 STATIC TEST UNITS RED TO IDENTIFY AS TEST HARDWARE. QCE 8-30-82

① Vendor notified to comply with notes on drawing

8-31-82

9/2/82
9-1-82

0690 A E

GENERAL ELECTRIC
SPACE SYSTEMS OPERATIONS

AE 0691

NONCONFORMANCE REPORT

Page 1 of

1. T-SA	2. Date Orig. 10-4-82	3. Location Operation EVENDALE GE-AEPD	4. Contract No. DEN3-153	5. SO No. 7150-L2-6AH3-00	6. Ref. MRCQ. EV 10182
7. Top Assy. MANIFOLD, P.S.	8. Dwg No. 47E382057-P1 AR O	9. S.N. —	10. Supplier & Code No. GE - AEPD	11. Buyer McDONNELL	12. P.C. Code 811
13. Itemt Item SAME	14. Dwg No. AR SAME	15. S.N. —	16. Supplier & Code No. GE - AEPD	17. Vehicle No. PROTO	18. Source Insp. ☐ Cont ☐ GE
19. P.O. No. FMP-111	20. Lot No. 1 / 21. Lot Sam. 1 / 22. No. Insp 1	23. No. Rej. 1	24. Test/Insp Spec. Para. DWG 47E382057	25. Last Oper. COMPLETE	26. Type Test/Insp FINAL INSP

27. Description of Nonconformance

① 2.750 DIM (ZONE F6) MEASURES 2.759
② .875 DIM (ZONE F14) MEASURES .857
③ 3.625 DIM (ZONE E14) MEASURES 3.633 AND 3.630
④ 1.750 DIM (ZONE D8) MEASURES 1.762
⑤ 3.500 DIM (ZONE C8) MEASURES 3.518
NOTE: TOLERANCE ON ALL ABOVE DIMS IS ±.005"

28. Prelim Disp Code	29. Resp.	30. Date & Stamp
MRB	GE	

31. Probable Cause

OPERATOR ERROR.

32. Originator: O. Chafer   Date: 10-4-82

33. Validated by   Date

34. Disposition Instructions

① thru ⑤ ACCEPT AS IS. DISCREPANCIES WILL NOT PRESENT ~~A~~ PROBLEM WHEN MOUNTING.

T. Kuhl   O. Chafer
10/4/82   10-4-82

35. Corrective Action Statement

OPERATOR CAUTIONED TO USE MORE CARE IN FUTURE.

36. Corrective Action Designator: O. Chafer /   Date: 10-4-82

37. Recurrency No.

Approvals

38. Engineering Date	39. Quality Date O. Chafer 10-4-82	40. Customer Date	41. PROG. OFF. Date

42. D.A.T.E. CODES	DEF ☐☐☐	CSP ☐	LOC ☐☐☐	RESP ☐☐☐	CLASS ☐☐	CA ☐☐	TT ☐☐

Form 86235 (Rev 5.78)

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GENERAL ELECTRIC
SPACE SYSTEMS OPERATIONS

NONCONFORMANCE REPORT

AE 0693

Page 1 of

Rep. MD-[illegible]	2. Date Discov. 10-28-82	3. Location Operation AEPD-EVENDALE	4. Contract No. DEN3-153	5. [illegible] No. 7150-L2-6AC3-00	6. Ref. [illegible]
Item Insp/Tested COLLAR	8. Dwg. No. 47B382083 [illegible] 0	9. S/N N/A	10. Supplier & Code No. AEPD-EVENDALE	11. Buyer McDONALD	12. P.C. [illegible] 872
Failed Item SAME	14. Dwg. No. SAME [illegible]	15. S/N N/A	16. Supplier & Code No. SAME	17. Vehicle No. DEV. TEST	18. Source Insp. ☐ Govt. ☐ GE
P.O./W.O. No.	20. Lot No. 1	21. Lot Size 68	22. No. Insp. 68	23. No. Rej. 7	24. Test/Insp. Spec. Para. PER DRAWING
25. Last Oper. COMPLETE	26. Type Test/Insp FINAL INSP				

7. Description of Nonconformance

① 1.140/1.135 DIA. HOLE OVERSIZE ON SEVEN (7) PIECES
AS FOLLOWS:
1 – 1.141
3 – 1.143
1 – 1.148
1 – 1.153
1 – 1.168

28. Proper Resp. Code	29. Resp.	32. Code & Stamp
MRB	GE	

Problem Cause: OPERATOR ERROR

Originator: A. CHEDDAR Date: 11-1-82

33. Validated by Date

Disposition Instructions

① Accept all seven (7) pieces "as is". Discrepancies will have no serious adverse effects on test data.
V. Williams 11/2/82
A. Cheddar 11/2/82

Corrective Action Statement

Operator cautioned to use more care in future.

36. Corrective Action Designee Date: A. Cheddar 11/2/82

37. Recurrency No.: 0

MRB Approvals:

38. Engineering Date: 11/2/82

39. Quality Date: A. Cheddar 11-2-82

40. Customer Date

41. Gov. [illegible] OFF. Cro 11/2/82

Form 88235 (Rev 5.78)

42. D.A.T.E. CODES	DU ☐☐☐	DISP ☐	LOC ☐☐☐	RESP ☐☐☐	CAUSE ☐☐	CA ☐☐	TT ☐☐

0693 AE

Volume III
Book 2

APPENDIX F

GE - MOD-5A PROGRAM QUALITY ASSURANCE REQUIREMENTS FOR THE CONTROL OF RAW MATERIALS AND THE BLADE FABRICATION PROCESS

REV NO.
47A380074
CONT ON SHEET ii SH NO. i

TITLE MOD-5A WTG PROGRAM
QUALITY ASSURANCE REQUIREMENTS
FOR THE CONTROL OF RAW MATERIALS
AND THE BLADE FABRICATION PROCESS
FIRST MADE FOR

REVISIONS

MOD-5A WTG PROGRAM
QUALITY ASSURANCE REQUIREMENTS
FOR THE CONTROL OF
RAW MATERIALS AND THE BLADE FABRICATION PROCESS

A. Cheddar DATE: 12/15/82
Q. C. Engineer

H. Straub DATE: Dec 15, 1982
Test Engineer

DATE: 12/16/82
Mgr., Subcontracts

DATE: 12/17/82
Mgr., Design Engineering

DATE: 1/5/83
Mgr., Integration & Test

DATE: [illegible]
Program Manager

TOTAL NUMBER OF PAGES 17

(0913A)

SVTG 500
PRINTS TO

MADE BY A. Cheddar
ISSUED 1/10/83
APPROVALS
A. E. P. DIV OR DEPT.
KING OF PRUSSIA, PA LOCATION

PF-003-WB (3-81)
PRINTED IN U.S.A.

CODE IDENT NO.

REVISION LOG

This log identifies those portions of this document which have been revised since original issue. Revised portions of each page, for the current revision only, are identified by marginal striping.

Revision	Page No.	Paragraph Number(s) Affected	Rev. Date	Approval

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1.2 Scope 1

2.0 Applicable Documents

2.1 Drawings and Specifications 2

3.0 Requirements

3.1 Epoxy Materials 3
3.2 Veneer 5
3.3 Fabrication 9

SECTION 1

INTRODUCTION

1.1 PURPOSE

The purpose of this document is to establish minimum quality requirements which must be implemented by the blade manufacturer to insure the minimum acceptable level of control over the blade fabrication process and the raw materials utilized therein.

1.2 SCOPE

The requirements specified herein are intended for controlling all MOD-5A fabrication (development and prime) and are to be implemented by the manufacturer immediately. Non-compliance by the manufacturer may result in QA rejection of all items fabricated during the period between the issue of this specification and the implementation of these requirements.

SECTION 2.0

APPLICABLE DOCUMENTS

2.1 DRAWINGS AND SPECIFICATIONS

Appropriate detailed drawings or specifications applicable to the material or component being manufactured.

SECTION 3.0

REQUIREMENTS

3.1 EPOXY MATERIALS

3.1.1 Assign specification numbers and revision numbers to the specifications for each of the materials purchased. These shall be controlled documents and shall be changed only through a formal design change system.

3.1.2 The Purchase Order (P.O.) for materials shall reference the specification number and the revision number of the material being purchased.

3.1.3 The P.O. shall specify certification and/or test results to be supplied by the vendor.

a. Epoxide Equivalent Weight (EEW)
b. Viscosity
c. Color
d. Hydrolyzable Chloride

3.1.4 The material is to be identified by a lot or batch number and traceable to the P.O. on which purchased.

3.1.5 The P.O. shall have an inspection code indicating what inspections or tests are to be performed in incoming inspection.

a. Viscosity
b. Color

3.1 EPOXY MATERIALS (continued)

3.1.6 Material shall be held in a quarantine area until certifications have been received and incoming inspections and/or tests have been completed. A quarantine area is a controlled area where materials awaiting certifications, test results, or Material Review Board (MRB) disposition may be kept safely and with no danger of being inadvertently mixed with prime materials.

3.1.7 If certifications and inspections are satisfactory, the material shall be released to bonded stock or to production.

3.1.8 If certifications and inspections are not satisfactory, a Nonconformance Report (NR) will be written and the material will be held in quarantine until a disposition has been made by the Material Review Board (MRB).

3.1.9 Certifications, inspection data, P.O. copy, etc., will be maintained in QC files for a minimum period of 5 years. At the end of this period, the data shall be delivered to GE.

3.1.10 Materials with a limited shelf life shall have the date of manufacture, date of purchase and date of expiration of shelf life recorded for easy reference. Such materials shall be monitored continuously to insure that expired materials are not used in production.

3.1 **EPOXY MATERIALS** (continued)

3.1.11 Stock records shall indicate lot number, number of barrels or containers, individual container numbers or identification, date received, P.O. number, date withdrawn, amount withdrawn, job number to be used on. If a partial lot is withdrawn, care shall be taken to insure that all portions are identified to the original lot number or lot I.D.

3.1.12 When individual ingredients are mixed for use in production, an identifying number will be assigned to each batch or lot mixed. The lot numbers of all the individual ingredients used in this batch or lot shall be recorded and shall be traceable to this lot. Samples (5) of the mixed lot will be taken, identified with the appropriate lot I.D. number and tested to verify properties of the mixed lot.

a. Hardness

b. Gel Time

c. Color

3.2 **VENEER**

3.2.1 Assign specification numbers and revision numbers to the specifications for each of the materials purchased. These shall be controlled documents and shall be changed only through a formal design change system.

3.2 VENEER (continued)

3.2.2 The Purchase Order (P.O.) for materials shall reference the specification number and the revision number of the material being purchased.

3.2.3 The P.O. shall specify certification and/or test results to be supplied by the vendor.

a. Moisture Content Test Data

b. Grade - Each sheet shall be marked to indicate its grade. Marking shall be per veneer specification and shall be such that material used shall not impair the quality of the bond between adjacent sheets in the marked area.

c. Stiffness

d. Yield by Grade Data

e. Date Dried

f. Date Wrapped and Shipped

3.2.4 The material is to be identified by a lot or batch number and traceable to the P.O. on which purchased.

3.2.5 The P.O. shall have an inspection code indicating what inspections or tests are to be performed in incoming inspection.

a. Moisture Content Samples

b. Ultrasonic Grading Samples

c. Proper Identification and Marking

3.2 VENEER (continued)

d. Conformance to P.O. Requirements

e. Proper Packaging per Specification

f. Shipping Damage

3.2.6 Material shall be held in a quarantine area until certifications have been received and incoming inspections and/or tests have been completed. A quarantine area is a controlled area where materials awaiting certifications, test results, or Material Review Board (MRB) disposition may be kept safely and with no danger of being inadvertently mixed with prime materials.

3.2.7 If certifications and inspections are satisfactory, the material shall be released to bonded stock or to production.

3.2.8 If certifications and inspections are not satisfactory, a Nonconformance Report (NR) will be written and the material will be held in quarantine until a disposition has been made by the Material Review Board (MRB).

3.2.9 Certifications, inspection data, P.O. copy, etc., will be maintained in QC files for a minimum period of 5 years. At the end of this period, the data shall be delivered to GE.

3.2.10 Stock records shall indicate lot number, number of bunks, bunk numbers, date received, date withdrawn, job number (used on), and amount withdrawn. A "Bunk" is a term used to describe a bundle or stack of veneer of normal shipping size, usually between 250 and 300 sheets.

3.2 VENEER (continued)

Note: If a partial lot is withdrawn, the portion withdrawn and the portion remaining must be identified with the appropriate lot number or lot I.D.

3.2.11 When veneer is removed from storage stacks or bunks, moisture content samples representative of the entire bunk will be drawn, checked and recorded (MIN. 10 samples spaced equally from top to bottom of bunk or stack).

3.2.12 When veneer is being used for a "lay-up", an accurate record of "rough-peel" discards will be recorded and filed with data for that lot. A "lay-up" is a preliminary stacking of veneer for a particular job during which each piece of veneer is checked, trimmed to correct size, stacked dry and marked with a layer number and a position number or letter within that layer.

Note: Marking material shall be such that it will not impair the quality of the bond between adjacent sheets.

The veneer is then unstacked, coated with epoxy and returned to the same position in the final assembly that it occupied in the lay-up. "Rough peel" is a term used to describe sheets of veneer with a rougher than normal surface finish. A number of factors may contribute to this condition, included among which are the angle the cutting blade makes with a particular log, moisture content of the log, sharpness of the cutting blade, etc. Sheets of veneer having this abnormally rough finish are discarded. "Rough peel" should be measured rather than arbitrarily and visually determined.

3.2 **VENEER** (continued)

3.2.13 When more than one bunk of veneer is required for a lay-up, the bunks shall be blended to insure a uniform distribution of veneer from each bunk throughout the lay-up. Each lay-up must be planned on an individual basis after the total number of bunks required and the number of sheets per bunk have been determined. The lay-up is then planned to give the optimum distribution of veneer sheets from the various bunks.

3.3 FABRICATION

3.3.1 All fabrication shall be to written instructions describing the detailed operations to be performed in fabricating a billet or blade section.

3.3.2 Each individual participating in or contributing to the fabrication process shall be thoroughly familiar with the written instructions and shall be trained in the performance of his functions.

3.3.3 A copy of the written instructions shall be available at each work station.

3.3.4 A list of all machines, special tools, fixtures, inspection and/or test instrumentation required in the performance and/or monitoring of the process shall be prepared and attached to the process instruction. The process instruction shall include directions for operation and use of each item delineated.

3.3 **FABRICATION** (continued)

3.3.5 Detailed Quality Control inspections and tests shall be incorporated into the Process Instruction. These shall specify the type of inspection or test to be performed, the number of checks to be made or the number of samples to be taken, precise instructions for performing checks or selecting samples, acceptance/rejection criteria for each test or inspection performed, limits of process parameters for satisfactory operation, data to be recorded, ambient shop conditions, etc.

3.3.6 Prior to production of any hardware, a Process Readiness Review will be conducted with key personnel from GE serving as members of the Review Board. As a minimum, the Board will consist of representatives from Design Engineering, Quality Control Engineering and Manufacturing Engineering. The Review Team will verify the capability of the process to be performed based on adequate process development, process documentation and controls implemented, tools, equipment and facilities available and verified, personnel properly trained, and first article try-out verified.

3.3.7 As a minimum, the fabrication process shall include the following tests and/or inspections:

3.3 FABRICATION (continued)

3.3.7.1 Moisture Content (MC) - As veneer is being removed from a storage stack for use in a preliminary "build-up" or "lay-up", a minimum of ten (10) moisture content samples will be taken from each stack. Samples will be 10" square or 12" square pieces. One sample will be selected from the top layer and one from the bottom layer of the stack. The remaining eight samples will be taken from eight layers equally spaced between the top and bottom of the stack. Samples shall be identified by layer number from which drawn. Raw weight data and calculated values of moisture content shall be recorded for each sample by sample number. Moisture content values for each sample must be within TBD % of the mean for the ten samples taken. In addition, the mean must be within TBD % of the TBD % nominal value of moisture content desired in finished product.

3.3.7.2 Glue Spread Rate - Control parameters (upper and lower limits) for glue spread rates shall be established based on glue machine capability. Sufficient glue spread samples shall be taken at each machine start-up, prior to coating any prime veneer, to insure that glue spread rate is within specified limits and has been stabilized.

3.3 **FABRICATION** (continued)

3.3.7.2 (continued)

Glue spread samples will be 10" or 12" square pieces of veneer representative of the lot being processed. Spread rate shall be considered stabilized when three successive glue spread samples show rates within TBD % of each other. Each sample shall be identified with the job number being processed plus a consecutive serial number assigned in the order in which each sample was coated. Each sample shall be identified with its dry weight, its specified coated weight and its actual coated weight.

3.3.7.3 Glue Coating - Coating of prime veneer may commence after glue spread rate has been stabilized within process limits. Glue spread samples will be coated at regular intervals throughout the veneer coating cycle. One (1) glue spread sample shall be required for every two hundred and forty (240) square feet of veneer coated. Sample numbers, dry weight, coated weight and glue spread rates shall be recorded on appropriate data sheets and maintained on file with other data for the job being processed.

3.3 FABRICATION (continued)

3.3.7.4 Veneer Stacking - Depending on the size of the job, one or two senior technicians will be assigned responsibility for correctly stacking the coated veneer. He or they shall be responsible to insure that each sheet of veneer is placed in the exact location in which it appeared in the "lay-up". They shall insure that the correct face of the sheet faces upward; that the correct edge of the sheet goes against the stops or guides as appropriate; that sheets butt correctly and do not ride up and over each other; that allowable voids or knotholes are filled with epoxy as required; that sheets having scarfed edges are mated properly; that the number of layers is correct, and that the overall height of the build-up is within drawing dimensional requirements.

3.3.7.5 Vacuum Bagging - After the coated veneer has been properly stacked in the mold or on the table, the build-up shall be bagged and evacuated. To insure proper bagging, elimination of leaks and uniform pressure on the curing build-up, the vacuum inside the bag shall be monitored. A vacuum gage will be placed at each end of the assembly and at a maximum of ten (10) foot intervals along the length of the assembly.

3.3 FABRICATION (continued)

3.3.7.5 (continued)

Each gage will be calibrated against a master or reference gage and shall have an appropriate correction attached or assigned to it. Each gage shall be assigned a number and its number, location, actual reading and corrected reading shall be recorded on appropriate data sheets. Readings shall be taken and recorded at fifteen (15) minute intervals during the first hour after bagging. Readings shall be recorded at one-half (1/2) hour intervals for the next three (3) hours. Starting with the fifth hour, readings shall be recorded at one (1) hour intervals for the remainder of the cure cycle.

3.3.7.6 Ambient Conditions - During the course of a fabrication, the temperature and relative humidity in the shop or work area will be checked at one-half (1/2) hour intervals and recorded with other data for the job.

3.3.8 All data shall be recorded on standard data sheets which have been reviewed and approved for use by GE. All data shall bear the date and the signature of the individual recording the data. Job numbers, serial numbers and any other identifying numbers specified shall be recorded legibly on the data sheets. Data shall be reviewed and signed off by the Quality Control Engineer and stored in Quality Control files. Data shall be maintained on file for a period of at least five (5) years. At the end of this period, the data shall be delivered to GE.

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APPENDIX 6
GE - STATEMENT OF WORK FOR THE ERECTION OF THE MOD-5A WTG YAW, NACELLE AND BLADE SUBSYSTEMS

SOW-MOD-5A-WTG-033
SEPTEMBER 1983

STATEMENT OF WORK
FOR
ERECTION OF THE MOD-5A WIND TURBINE GENERATOR YAW, NACELLE AND BLADE SUBSYSTEMS

PREPARED: G. Drenker
G. Drenker

CONCURRED: J. W. Kern
J. Kern, Manager
Subcontract Management

9/13/83
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WTG Prototype Program

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Production and Assembly

APPROVED: L. Terrey
L. Terrey, Manager
WTG Site Installation and Test

APPROVED: ______________________
W. C. Pijawka, Manager
WTG Prototype Program

NO. OF PAGES: 36   ISSUED: SEPTEMBER 1983

REVISION LOG

This log identifies those portions of this document which have been revised since original issue. Revised portions of each page, for the current revision only, are identified by marginal striping or text notes.

Revision	Page No.	Paragraph Number(s) Affected	Rev. Date	Approval
1	General revision. Scope reduced to lifting of WTG components to final location only - Format changed.		10/18/83	LJ 11/3/83

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"B" MOD-5A CONPONENT AND SUBSYSTEM SIZES AND WEIGHTS - NACELLE

"C" MOD-5A COMPONENT AND SUBSYSTEM SIZES AND WEIGHTS - BLADE

"D" COMPONENT AND SUBSYSTEM SKETCHES

"E" AREA MAP

REFERENCE DRAWINGS

CIVIL SITE PLAN - MOD-5A WIND TURBINE HECO #27596A

CIVIL SITE PLAN - MOD-5A WIND TURBINE HECO #27597A

1.0 GENERAL

1.1 Introduction

This Statement of Work (SOW) establishes the requirements for the MOD-5A Wind Turbine Generator (WTG) site related erection tasks which are to be performed by the erection contractor. All site related construction and erection activities shall be conducted under the general direction of the GE site manager.

1.2 Description

The MOD-5A WTG system includes a tower mounted nacelle which contains the electrical generation equipment consisting of a rotor assembly, a speed-increaser gearbox, a variable speed generator subsystem and the instrumentation and control equipment. Power and signal cabling within the nacelle is routed through a sub-floor to a yaw slip ring assembly which serves as the tower/ nacelle interface. From the yaw slip ring, the cabling is routed down the tower and through the tower foundation to the Electrical Equipment Building (EEB) and from there through the site step-up transformer to the utility disconnect switches.

1.3 Scope

The scope of work defined in this SOW includes: a) transportation to the site of the erection and lifting equipment, b) lifting of the WTG subsystems to their final location, and c) teardown and return transportation of the lifting equipment. Transportation of the WTG components and subsystems and their assembly prior to lifting is not within the scope of this SOW.

The site location for the work is in the Kahuku area of Oahu, Hawaii. It is expected that this work will take place during the January - April, 1985 time period. It is possible inclement weather could delay the work during this January - April period, therefore an alternate work schedule is shown for the April - July time period, which is based on parallel yaw/nacelle erection and blade ground assembly activities. When selecting the type of lifting equipment to be used, the

1.3 Scope (continued)

ability to lift the yaw/nacelle and rotor from opposite sides of the tower should be considered.

The successful bidder for this MOD-5A WTG erection work must meet the requirements of all local, state and federal codes, regulations and ordinances covering requirements, permits, safety and environmental impact as well as all other statutory considerations which may apply.

Exhibits "A" through "C" tabulate the equipment to be erected. Exhibit "D" provides pictorial data on the equipment. GE will arrange for equipment tabulated in Exhibit "A", "B", and "C" to be transported to the WTG tower base and assembled to the desired configuration prior to lifting to the final location. All special lifting fixtures and spreader beams will be supplied by GE for the yaw, nacelle, gearbox and blade components and subsys- tems. All other rigging equipment shall be supplied by the bidder.

An area map showing the location of the site is provided in Exhibit "E". Preliminary site plans are shown on HECO drawings 27596 and 27597.

2.0 TASKS

The Erection Contractor shall provide and apply the manpower supervision, material, equipment, transportation and other resources needed for the purpose of accomplishing the tasks that are identified below, in accordance with a schedule that is consistent with the MOD-5A WTG Construction/Installation Activities Plan of this SOW.

2.1 Task 1

Review the design of the GE supplied lifting fixtures, spreader bars and sling attachment points to the components and subsystems and make recommendations as to the adequacy of these designs for the purpose intended.

2.2 Task 2

Issue written erection procedures for each lift to be performed. These procedures will be used by GE to conduct readiness reviews prior to each lift.

2.3 Task 3

Transport and erect the necessary cranes, and other lifting equipment to perform the necessary lifts in the most cost effective manner.

2.4 Task 4

Proof-load the lifting system prior to proceeding with any lift. The lifting system shall include slings, fixtures and spreader bars. Anchors will be provided in the tower foundation to which the lifting system with its load cells can be attached for proof loading. The Contractor shall provide recommendations regarding the method of proof-loading and the proof-load to be used. A proof-load greater than the heaviest lift is required.

The Contractor shall also provide recommendations for verifying proper operation and capacity of the lift system brakes.

2.5 Task 5

Lift and install the yaw, nacelle and blade components and subsystems as shown in Exhibits "A", "B" and "C" by the most cost effective method. The nacelle components and subsystems, as listed in Exhibit "B", may be lifted and installed per the lifts shown in Column A, B or C. A single lift, as shown in column C is preferred but may not be the most cost effective method.

The blade lift of 300,000 pounds, as shown in Exhibit "C", is a single lift. This weight cannot be reduced.

The component and subsystem sizes and weights, as shown in the tables and figures, do not contain any fixtures, spreader bars and slings weights. It is estimated, at this time, that the fixtures and spreaders will add 15% to each lift weight.

Interface heights are:

Yaw to Tower: 218.73 Ft.
Nacelle to Upper Yaw Structure: 230.15 Ft.
Blade Hub Height: 245.0 Ft.

The tower is a 14 1/2' cylindrical shell from the yaw structure to 50' above the ground. This shell then bells out to a diameter of 22 1/2' at the foundation interface (ground level).

The yaw structure-tower interface girth weld is the responsibility of the tower fabricator and installer.

2.6 Task 6

Remove and transport all of the Contractor's equipment at the completion of erection.

3.0 DOCUMENTS TO BE PROVIDED BY GE

3.1 Drawings

a. Site Layout and Topographic Drawings
b. Yaw Assembly drawing
c. Yaw-Tower Interface Drawing
d. Nacelle Assembly Drawing
e. Nacelle-Yaw Interface Drawing
f. Blade Assembly Drawing
g. Blade - Yoke Interface Drawing
h. Yaw Lifting Fixture Drawing
i. Nacelle Subsystem Lifting Fixture Drawings
j. Blade Lifting Fixture Drawing

4.0 DOCUMENTATION TO BE PROVIDED BY CONTRACTOR

The Erection and Installation Contractor shall provide the documents identified in Table 4-1 (Data Requirements List) of this SOW, at the times and in the quantities specified in the Table.

TABLE 4-1 DATA REQUIREMENTS LIST FOR ERECTION CONTRACT

DOC. NO.	DELIVERABLE DOCUMENT(S)	TIME(S) OF DELIVERY	DELIVER TO (ADDRESSEE "A")	COPY TO (ADDRESSEE "B")	NO. OF COPIES	
					TO "A"	TO "B"
EI-1	ERECTION AND INSTALLATION PROJECT SCHEDULE	30 DAYS AFTER CONTRACT AWARD. SUBSEQUENT UPDATES AS APPROPRIATE.	GE SITE MANAGER	GE SUBCONTRACT ADMINISTRATOR	5	1
EI-2	WEEKLY PROGRESS REPORTS	WEEKLY THROUGHOUT CONTRACT PERIOD.	GE SITE MANAGER	GE SUBCONTRACT ADMINISTRATOR	5	1
EI-3	MONTHLY FINANCIAL REPORTS	MONTHLY, BY 10TH of FOLLOWING MONTH, THROUGHOUT CONTRACT PERIOD.	GE SUBCONTRACT ADMINISTRATOR	GE SITE MANAGER	2	1
EI-4	DOCUMENTATION FOR PERMITS	AS REQUIRED BY COGNIZANT REGULATORY BODIES.	GE SITE MANAGER	GE SUBCONTRACT ADMINISTRATOR	2	1
EI-5	ERECTION/INSTALLATION PROCEDURES	60 DAYS PRIOR TO LIFT DESCRIBED IN PROCEDURE.	GE SITE MANAGER	GE SUBCONTRACT ADMINISTRATOR	5	1

5.0 SCHEDULE

A preliminary schedule for MOD-5A construction activities is shown in Figure 5-1. This schedule shows an alternative sequence starting with tower erection in April 1984. This alternative sequence may be used if inclement weather dictates delaying construction work.

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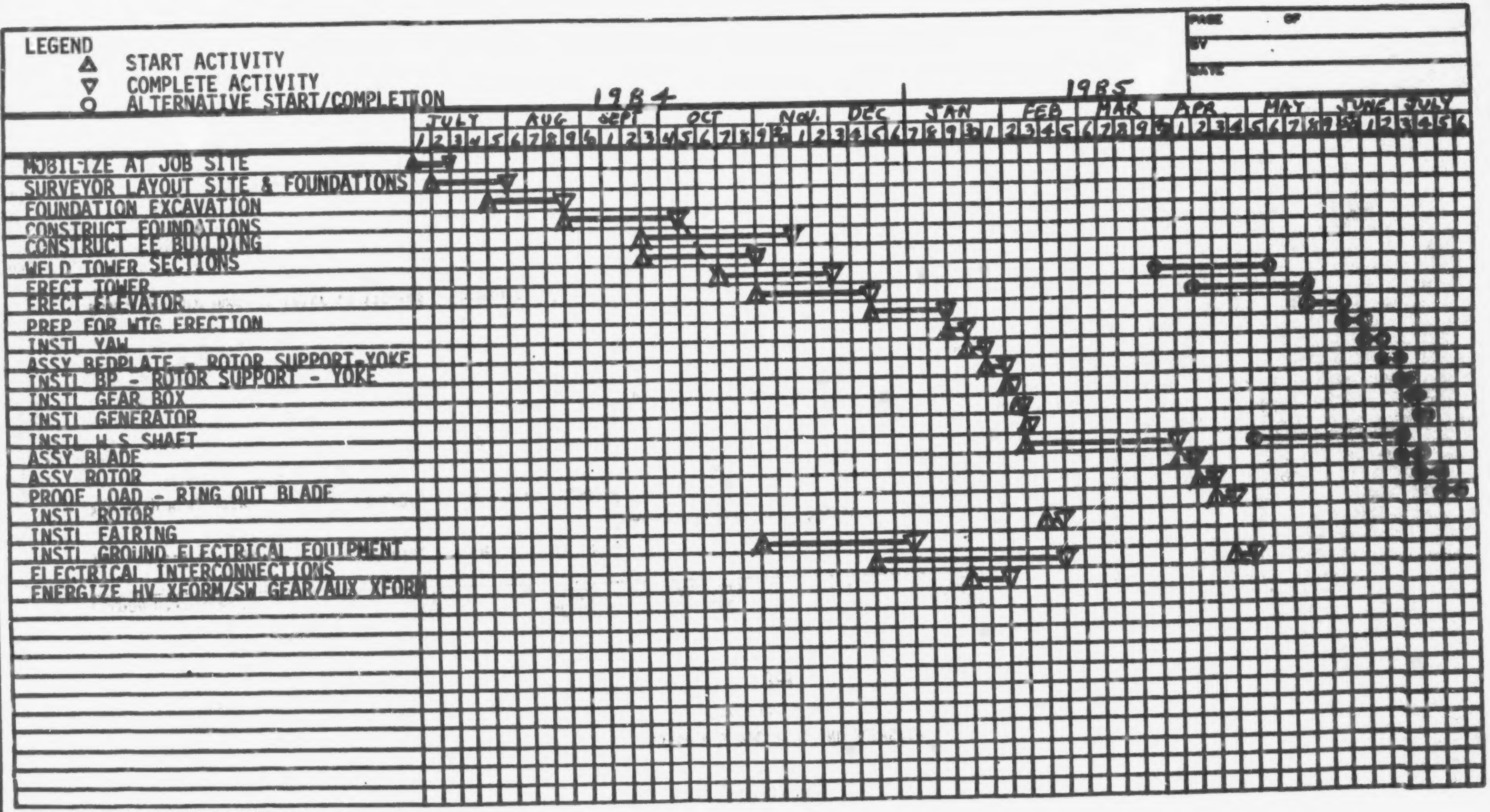

FIGURE 5-1: MOD-5A WTG CONSTRUCTION, ACTIVITIES PLAN

EXHIBIT "A"

MOD-5A WTG COMPONENT AND SUBSYSTEM
SIZES AND WEIGHTS
YAW

COMPONENT/SUBSYSTEM	SIZE (FT.)	WEIGHT (LBS)	GROUND ASSEMBLY	LIFT	FIGURE NO.
Yaw Structure Assy.	16' Dia. x 12'H	53,100	56,600 →	56,600	5
Yaw Slip Ring Assy.	11 1/2'L x 3'W x 3'TK	3,500			5

NOTE: Figure Numbers refer to figures in Exhibit "D".

EXHIBIT "B"

MOD-5A WTG COMPONENT AND SUBYSTEM
SIZES AND WEIGHTS
NACELLE

COMPONENT/SUBSYSTEM	FIG. NO.	SIZE (FT.)	WEIGHT (LBS)	GROUND ASSEMBLY	LIFT "A"	ADDITIONAL GROUND ASSEMBLY	LIFT "B"	ADDITIONAL GROUND ASSEMBLY	LIFT "C"
Bedplate Base	6	44'L x 14'W x 8'H	130,000	278,000	Fig. 15 278,000	441,500	Fig. 17 441,500	731,500	Fig. 18 735,100
Side Plates (2)	7	20'L x 14'W x 1'TK	16,300 ea.						
Rotor Adapter	8	14'L x 14'W x 5'TK	56,000						
High Voltage Cabinet	-	12'L x 3'W x 8'H	1,200						
Electronic Cabinet	-	8'L x 3'W x 6'H	1,000						
Lubrication Module	-	15'L x 8'W x 6'H	2,000						
Generator	9	14'L x 8'W x 8'H	47,200						
Walkways and Platforms	-	Loose Parts	8,000						
Gearbox	10	17'L x 10'W x 12'H	127,000	140,000	140,000				
Top Plate	11	20'L x 14'W x 1'TK	9,000	12,000	12,000				
Auxiliary Maint. Crane	12	--	3,000						
High Speed Shaft Assy.	13	4'L x 3' Dia.	1,500	1,500	1,500				
Rotor Slip Ring	-	5'L x 1'W x 2'H	500	500	500				
Fairing Assy. (Palletized)	-	21'L x 8'W x 8'H	8,800	9,500	9,500				
Aircraft Warning Lights	-	3'L x 2'W x 1'H	100						
Wind Sensor Mast Assy. (2)	-	30'L x 2'W x 2'H	300 ea.						
Yoke Structure Assy.	14	25'L x 12'W x 12'H	210,000	290,000	Fig. 16 290,000	290,000	290,000		
Low Speed Shaft Assy.	-	16'L x 5'Dia.	75,000						
Aileron Hydraulics Assy.	-	15'L x 5'W x 3'H	5,000						

NOTE: Figure Numbers refer to figures in Exhibit "D".

EXHIBIT "A"

MOD-5A WTG COMPONENT AND SUBYSTEM
SIZES AND WEIGHTS
YAW

COMPONENT/SUBSYSTEM	SIZE (FT.)	WEIGHT (LBS)	GROUND ASSEMBLY	LIFT	FIGURE NO.
Yaw Structure Assy.	16' Dia. x 12'H	53,100	56,600 →	56,600	5
Yaw Slip Ring Assy.	11 1/2'L x 3'W x 3'TK	3,500			5

NOTE: Figure Numbers refer to figures in Exhibit "D".

EXHIBIT "D"

COMPONENT AND SUBSYSTEM SKETCHES

This exhibit includes pictorial data as follows:

FIGURE NO.	TITLE
FIGURE 1	(NOT USED)
" 2	(NOT USED)
" 3	PROPOSED FOUNDATION
" 4	TOWER ELEVATION
" 5	YAW SUBSYSTEM
" 6	BEDPLATE
" 7	ROTOR ADAPTER SIDE PLATE
" 8	ROTOR ADAPTER
" 9	GENERATOR
" 10	GEARBOX
" 11	ROTOR ADAPTER TOP COVER
" 12	AUXILIARY MAINTENANCE CRANE
" 13	HIGH SPEED SHAFT
" 14	YOKE STRUCTURE ASSEMBLY
" 15	NACELLE ASSEMBLY
" 16	YOKE ASSEMBLY
" 17	NACELLE ASSEMBLY
" 18	NACELLE ASSEMBLY WITH YOKE AND LOW SPEED SHAFT
" 19	BLADE ASSEMBLY
" 20	BLADE ERECTION

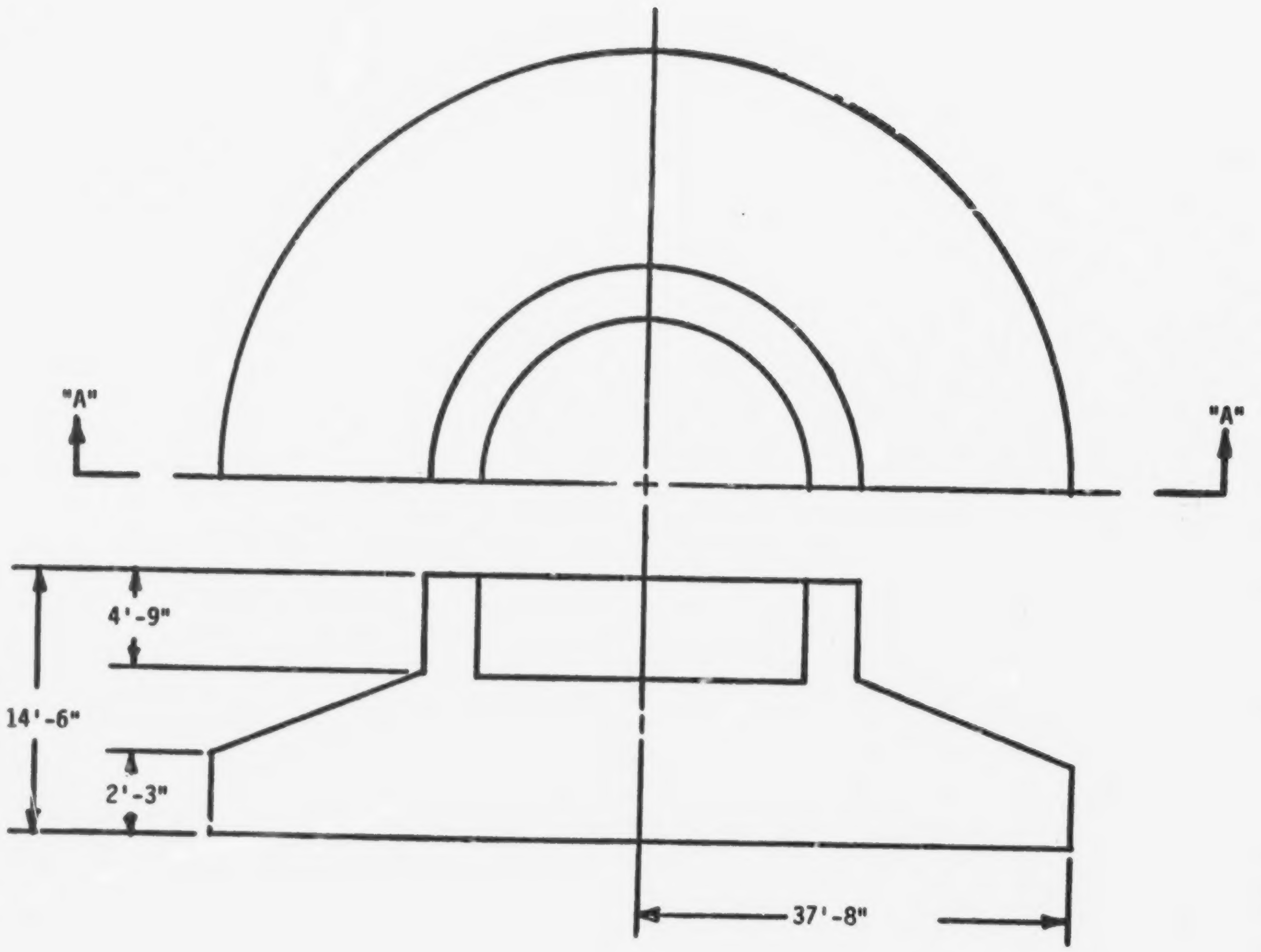
"A"
"A"
4'-9"
14'-6"
2'-3"
37'-8"

Figure 3 Proposed Foundation

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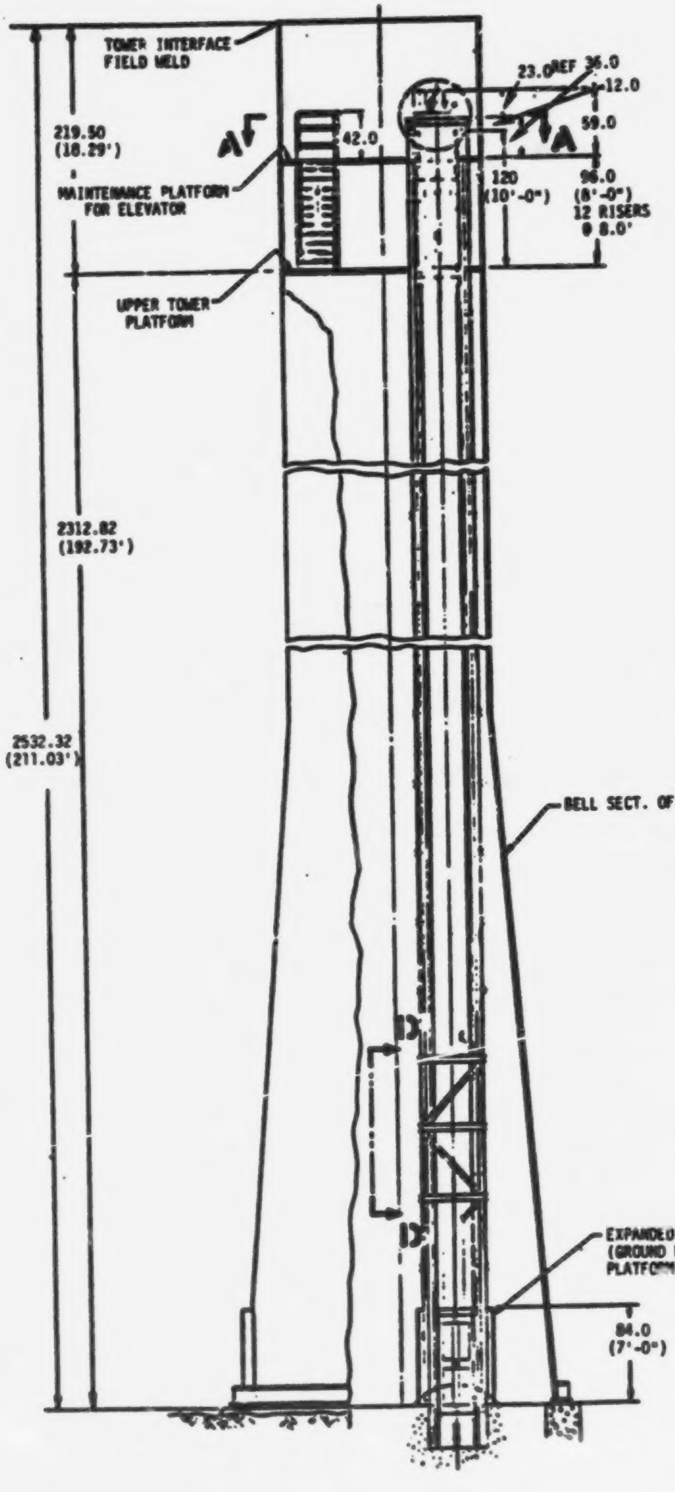
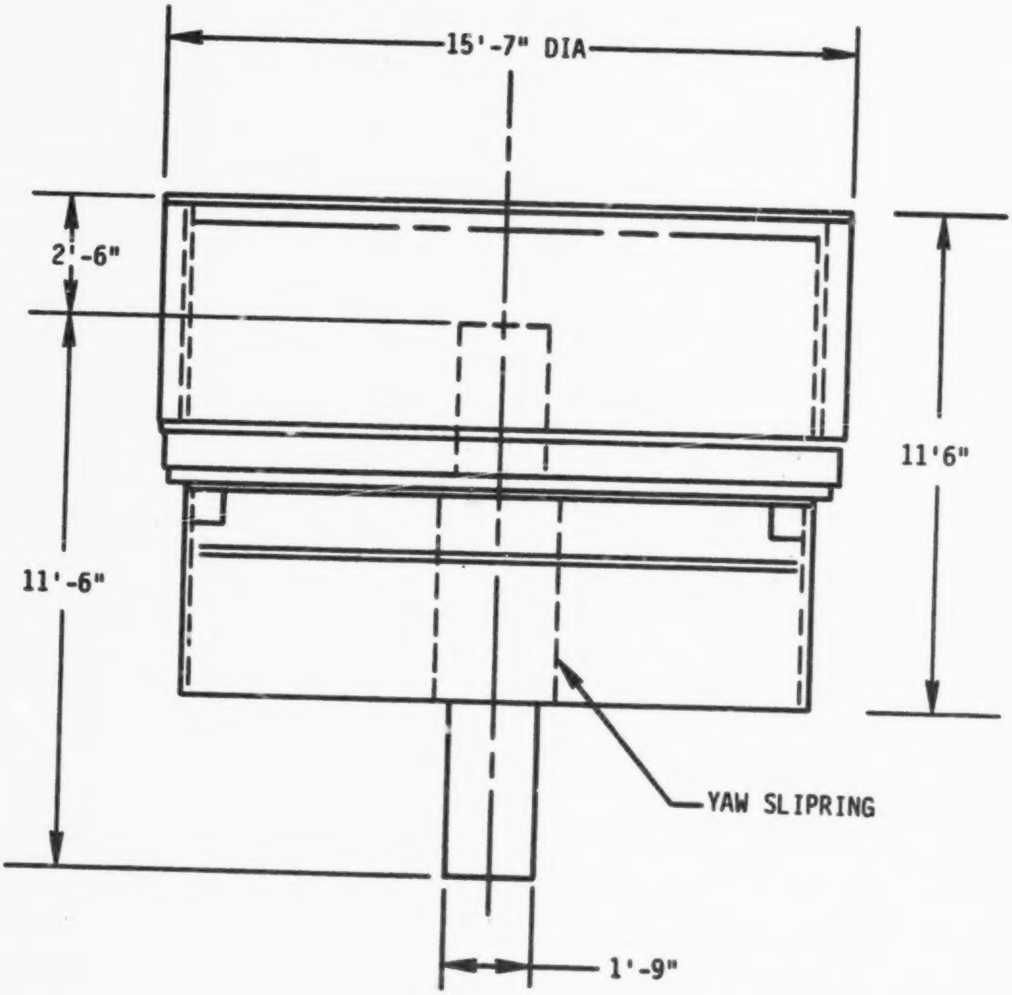

TOWER INTERFACE FIELD WELD
23.0 REF
36.0
12.0
59.0
42.0
A
A
219.50 (18.29')
MAINTENANCE PLATFORM FOR ELEVATOR
120 (10'-0")
96.0 (8'-0") 12 RISERS @ 8.0'
UPPER TOWER PLATFORM
2312.82 (192.73')
2532.32 (211.03')
BELL SECT. OF TOWER (REF)
EXPANDED WIRE CAGE-FRAMED (GROUND FLR & UPPER TOWER PLATFORM)
84.0 (7'-0")

Figure 4 Tower Elevation



15'-7" DIA
2'-6"
11'-6"
11'6"
YAW SLIPRING
1'-9"

Figure 5 Yaw Subsystem

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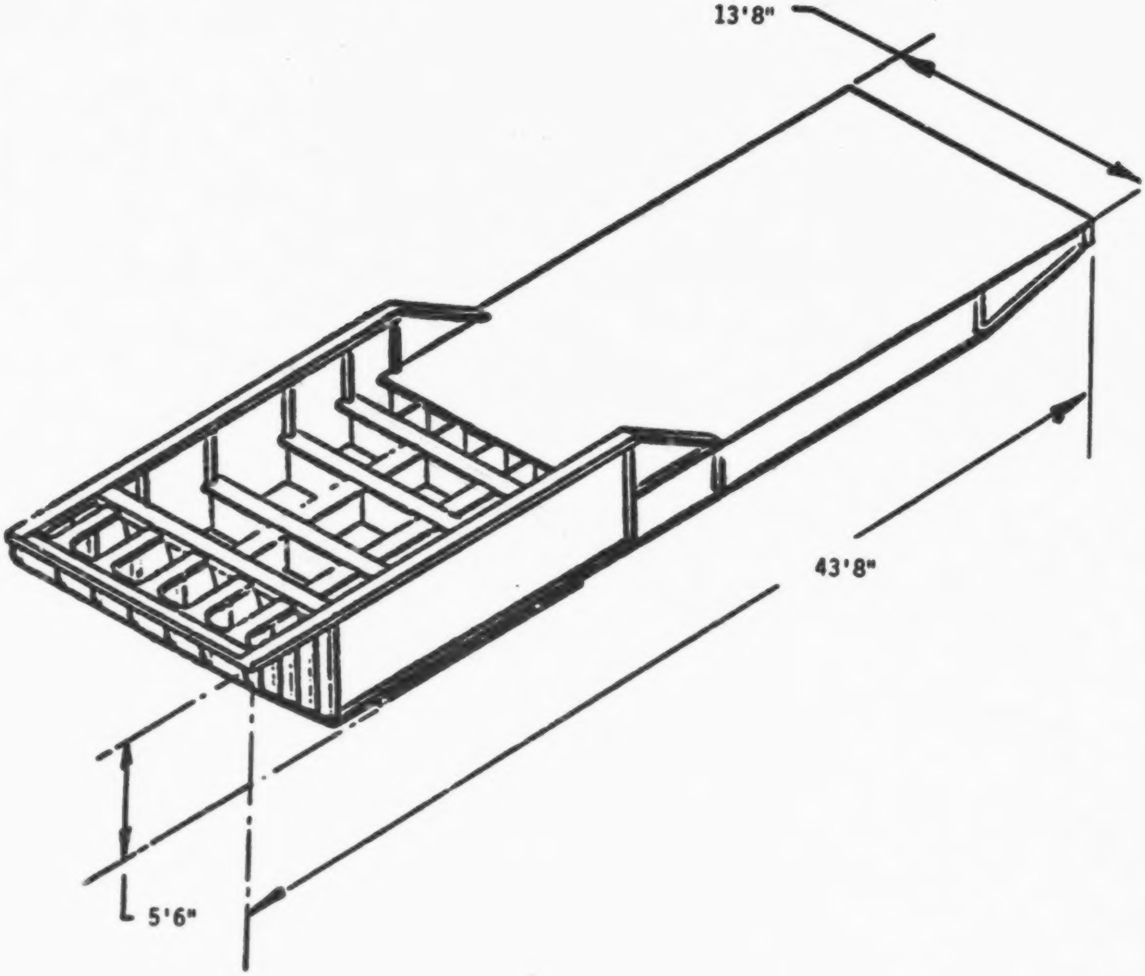

Figure 6 Bedplate

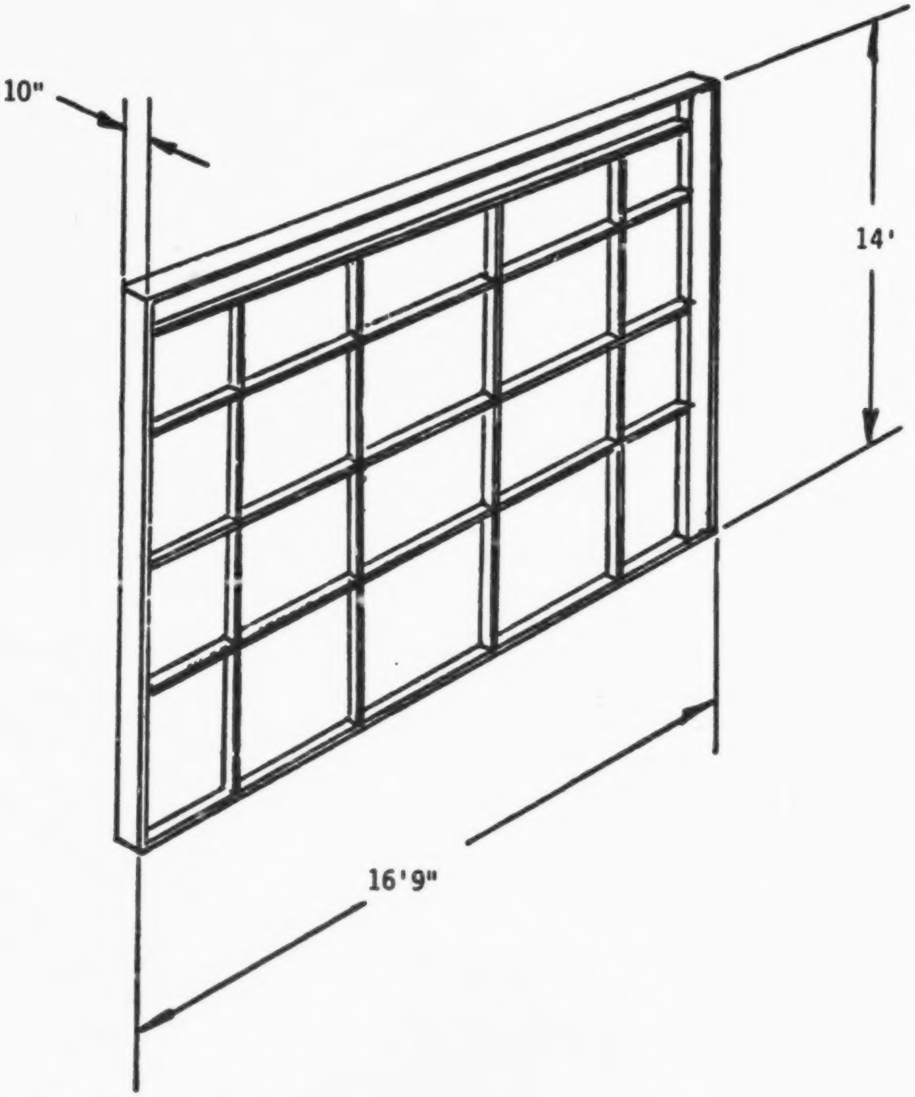

Figure 7 Rotor Adapter Side Plate

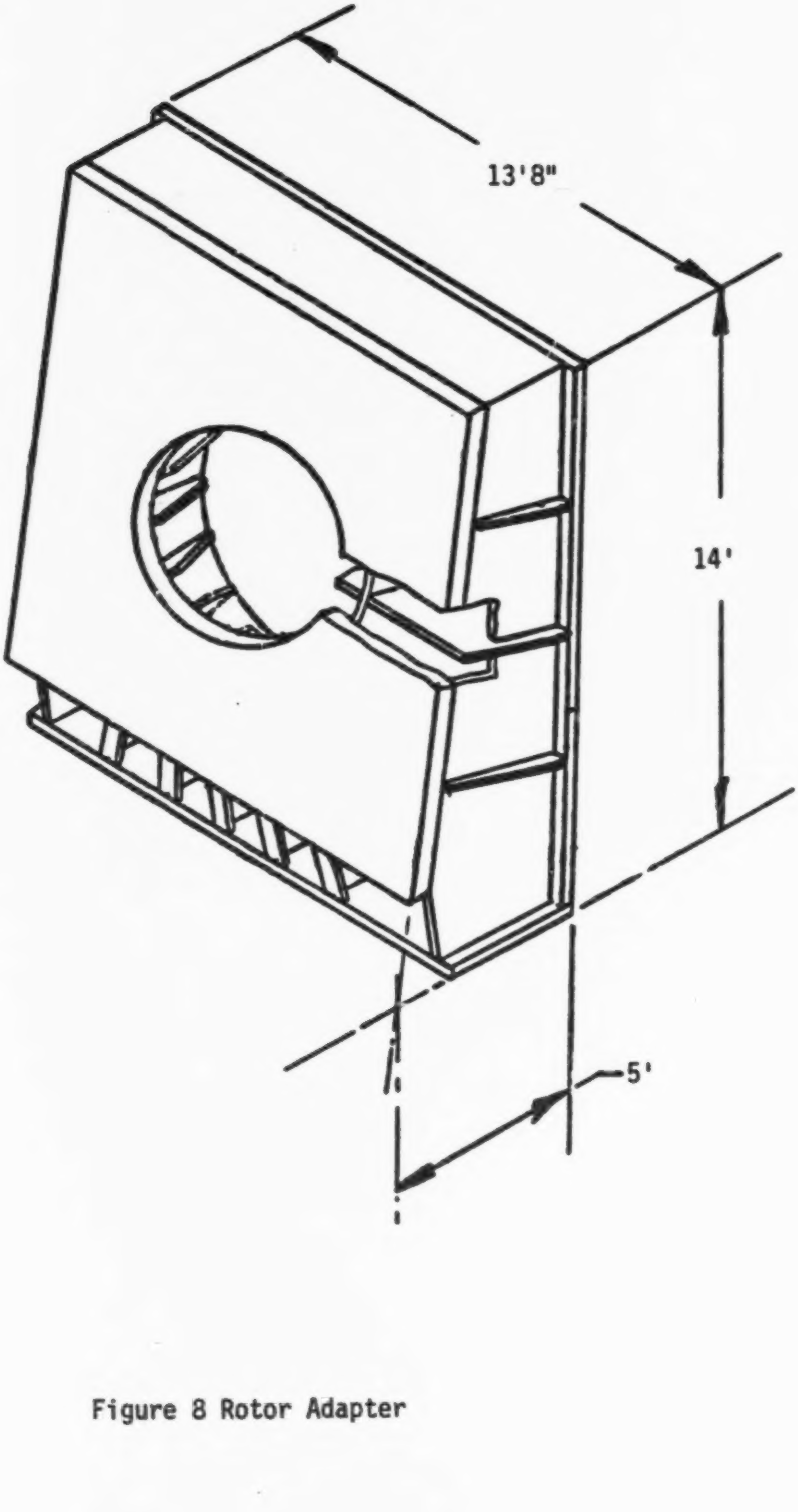

Figure 8 Rotor Adapter

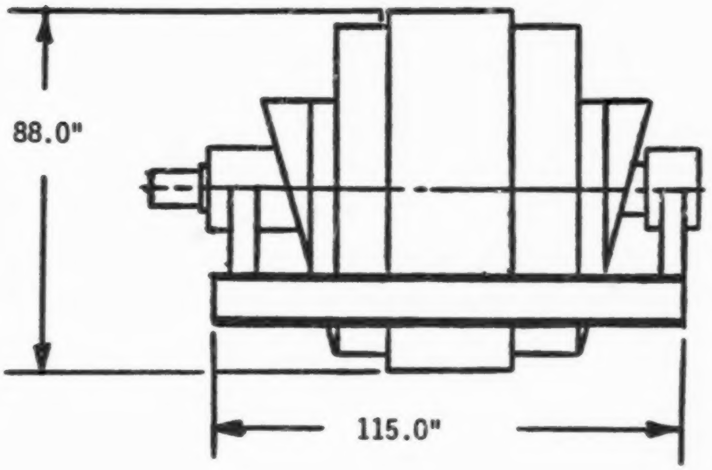

Figure 9 Generator

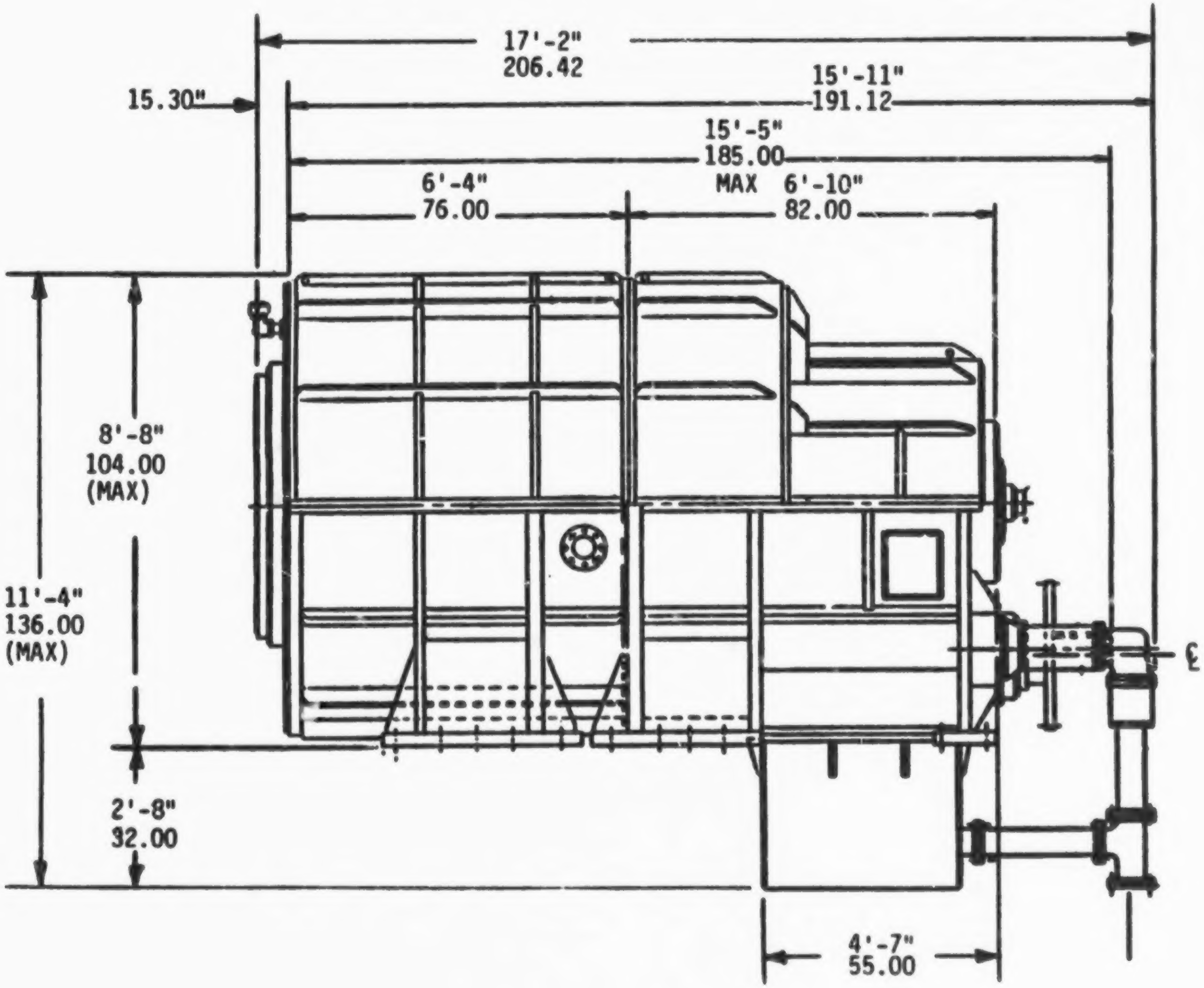
17'-2"
206.42
15'-11"
191.12
15.30"
15'-5"
185.00
6'-4"
76.00
MAX 6'-10"
82.00
8'-8"
104.00
(MAX)
11'-4"
136.00
(MAX)
2'-8"
32.00
4'-7"
55.00
℄

Figure 10 Gearbox

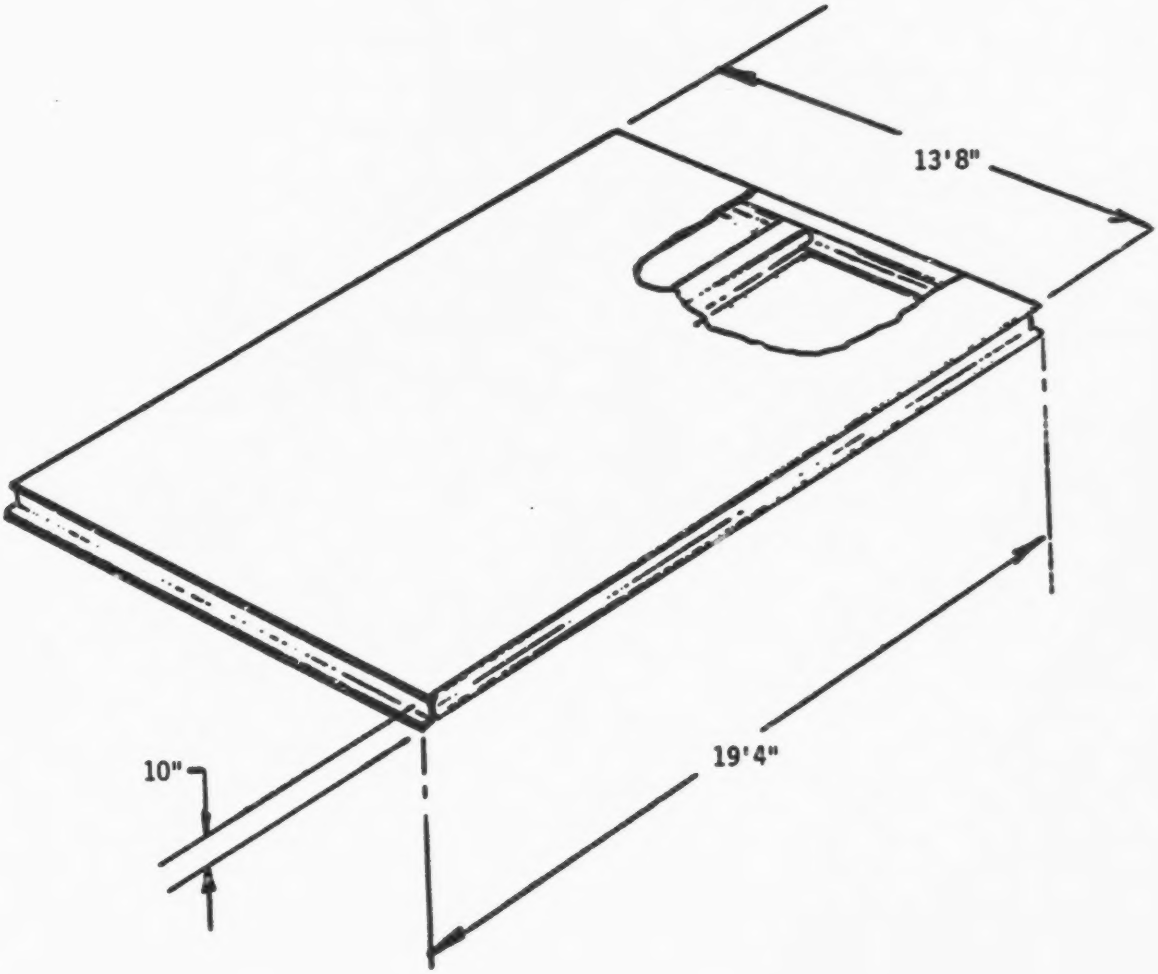

Figure 11 Rotor Adapter Top Cover

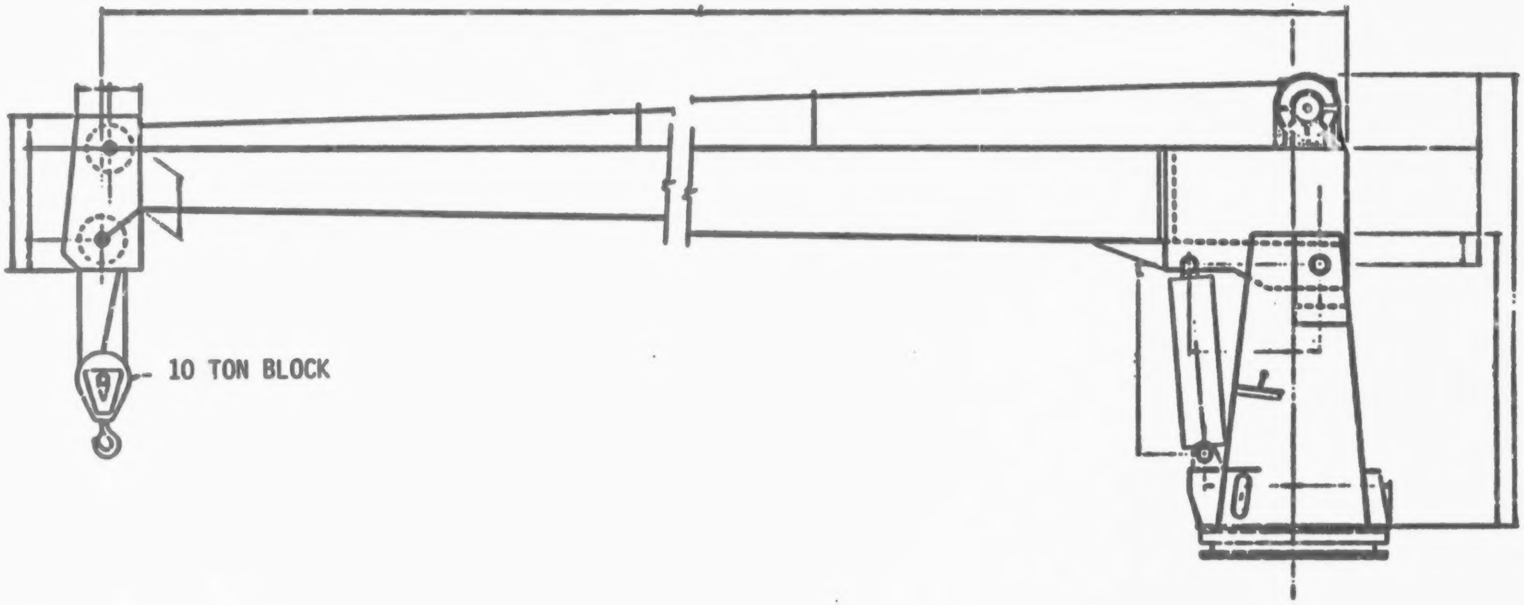
10 TON BLOCK

Figure 12 Auxiliary Maintenance Crane

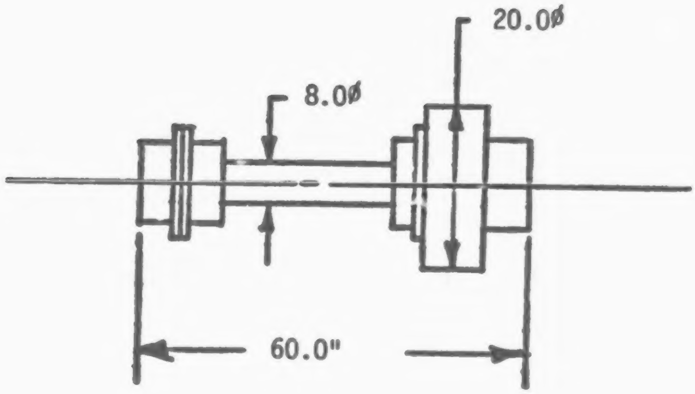
20.0Ø
8.0Ø
60.0"

Figure 13 High Speed Shaft

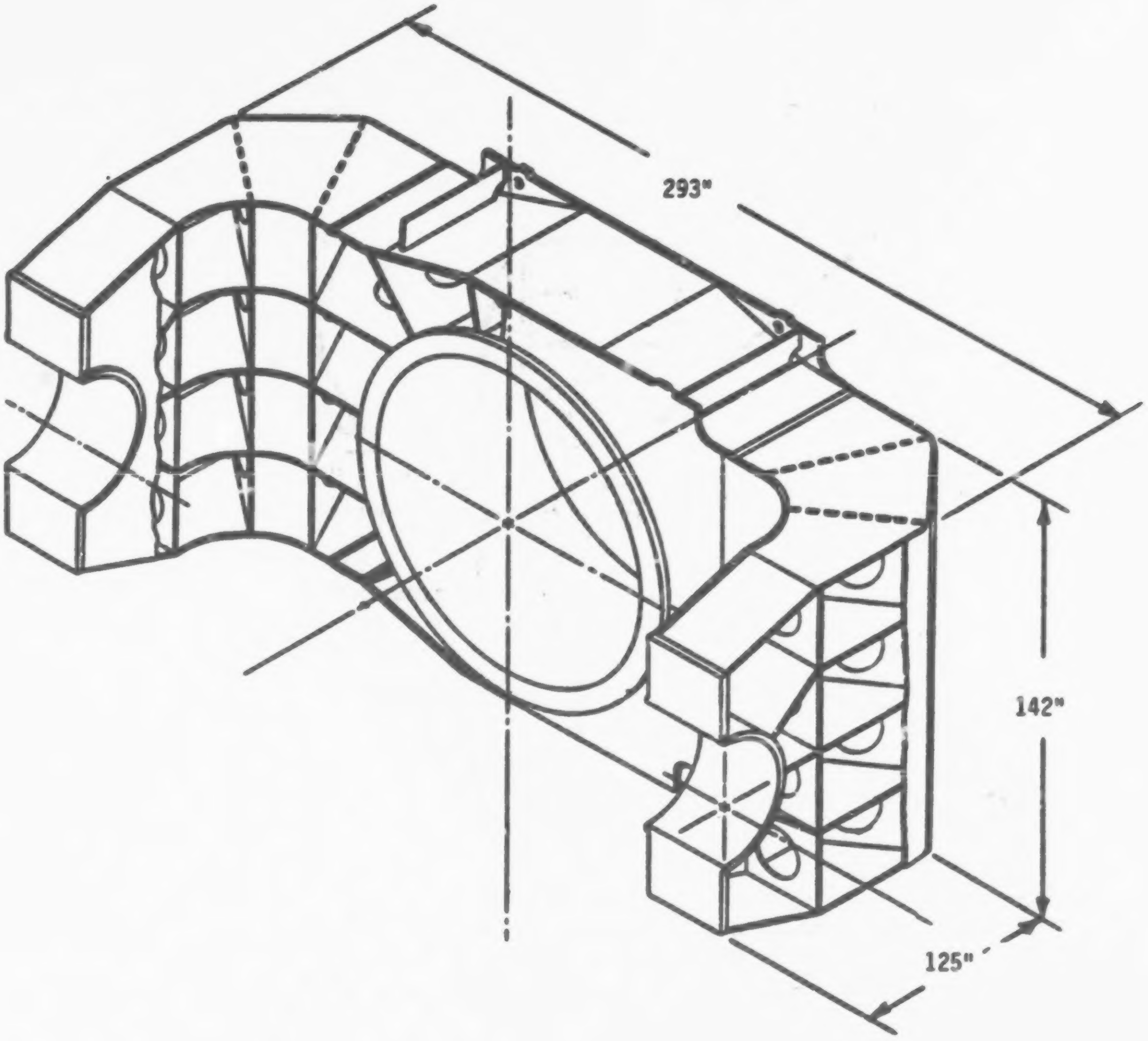

Figure 14 Yoke Structure Assembly

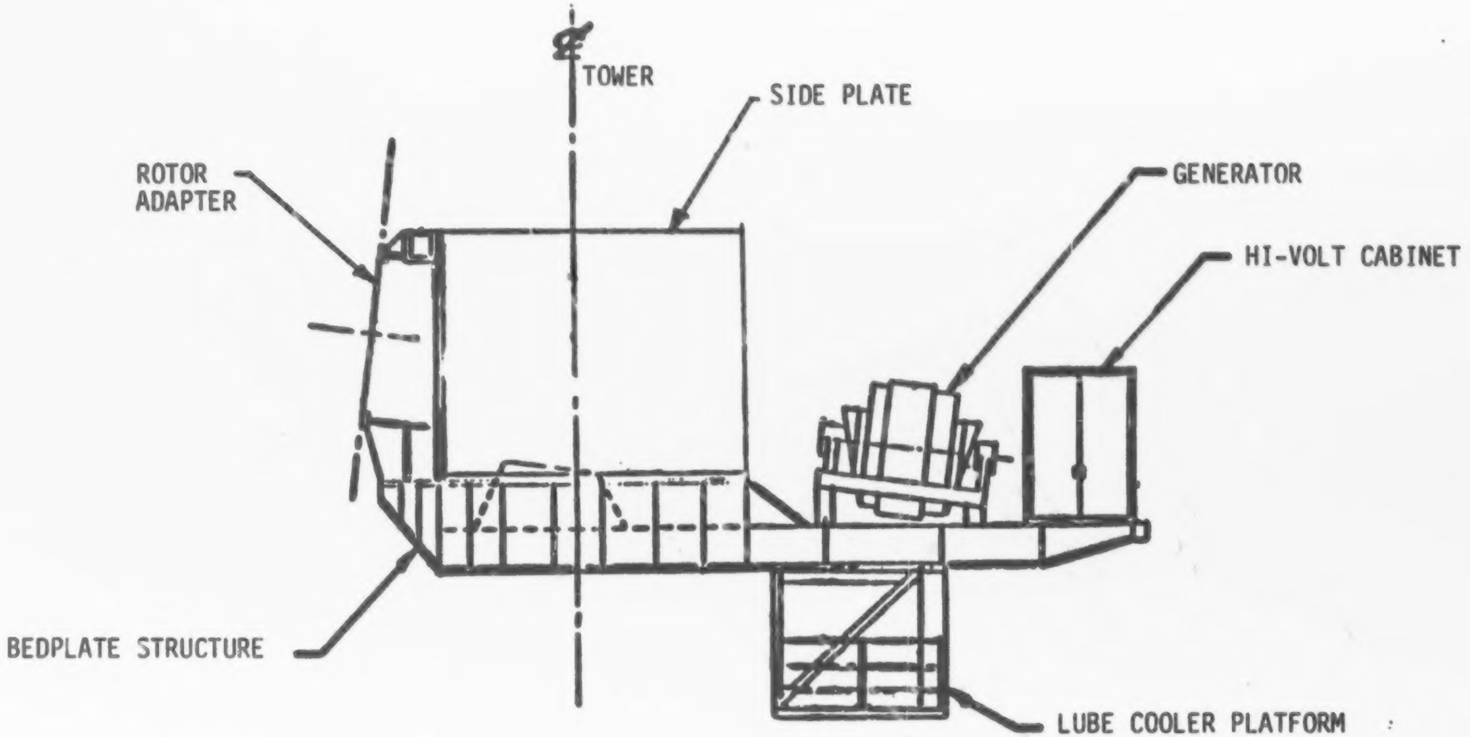
℄ TOWER
SIDE PLATE
ROTOR ADAPTER
GENERATOR
HI-VOLT CABINET
BEDPLATE STRUCTURE
LUBE COOLER PLATFORM

Figure 15 Nacelle Assembly

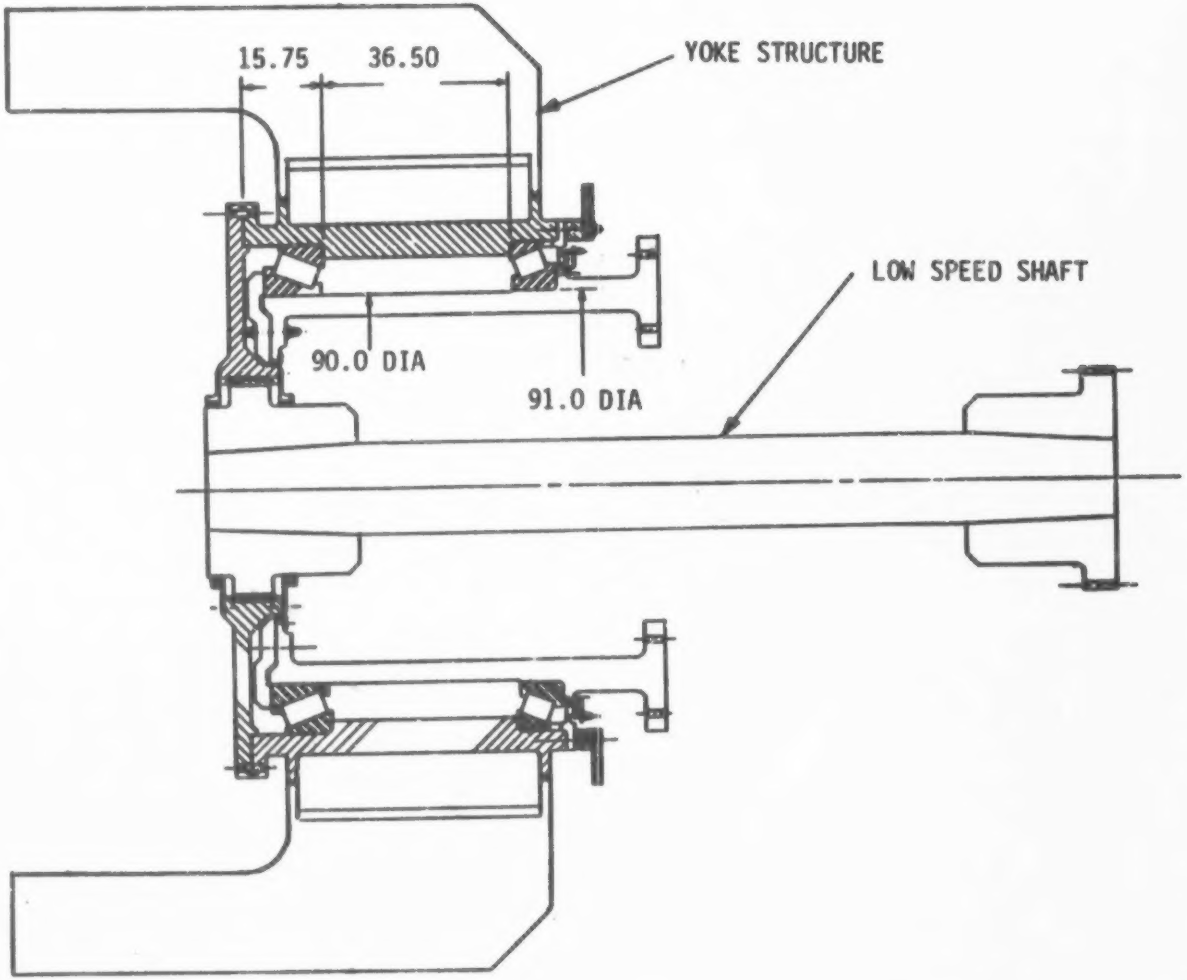
15.75
36.50
YOKE STRUCTURE
LOW SPEED SHAFT
90.0 DIA
91.0 DIA

Figure 16 Yoke Assembly

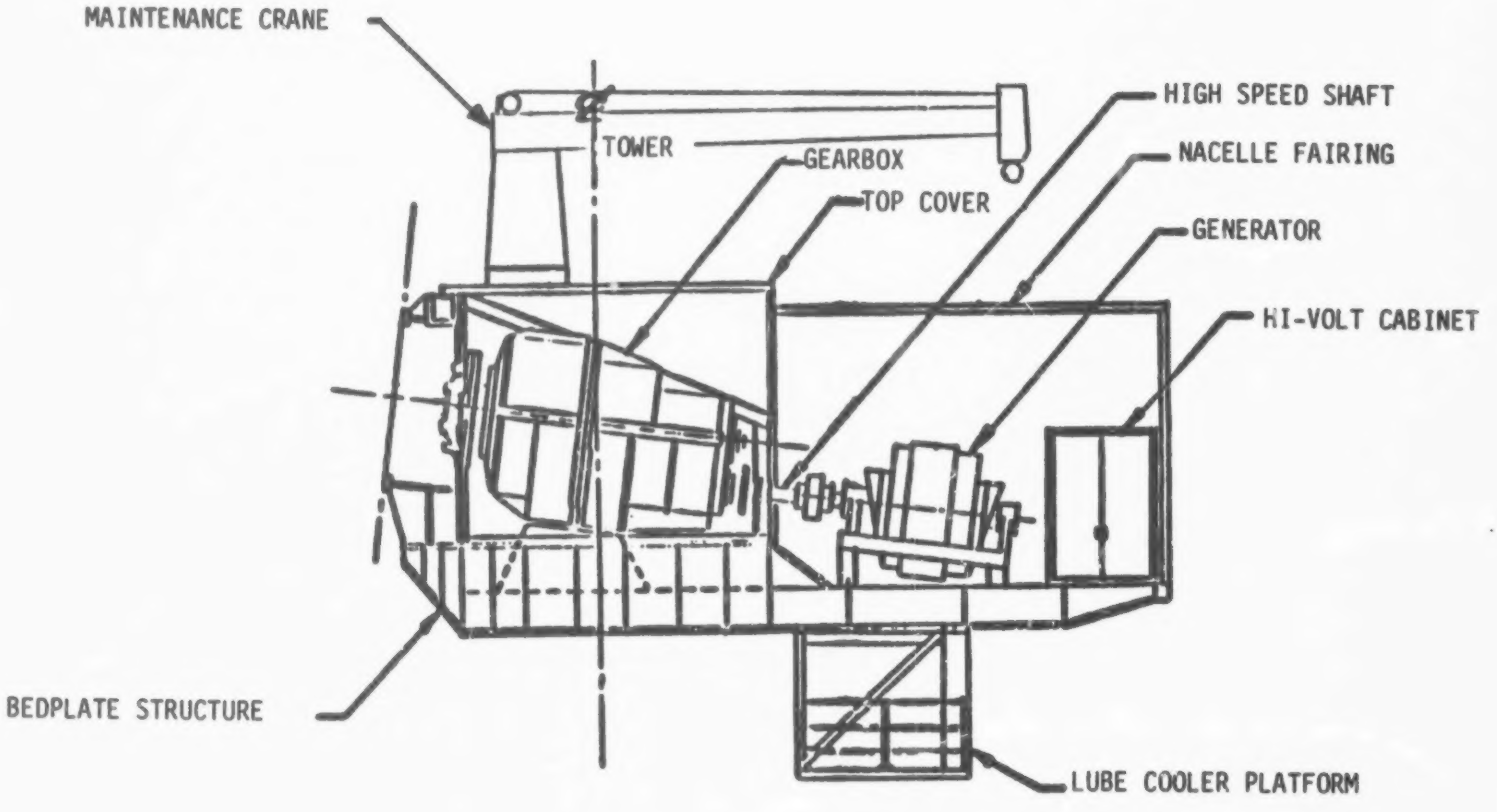
MAINTENANCE CRANE
TOWER
GEARBOX
TOP COVER
HIGH SPEED SHAFT
NACELLE FAIRING
GENERATOR
HI-VOLT CABINET
BEDPLATE STRUCTURE
LUBE COOLER PLATFORM

Figure 17 Nacelle Assembly

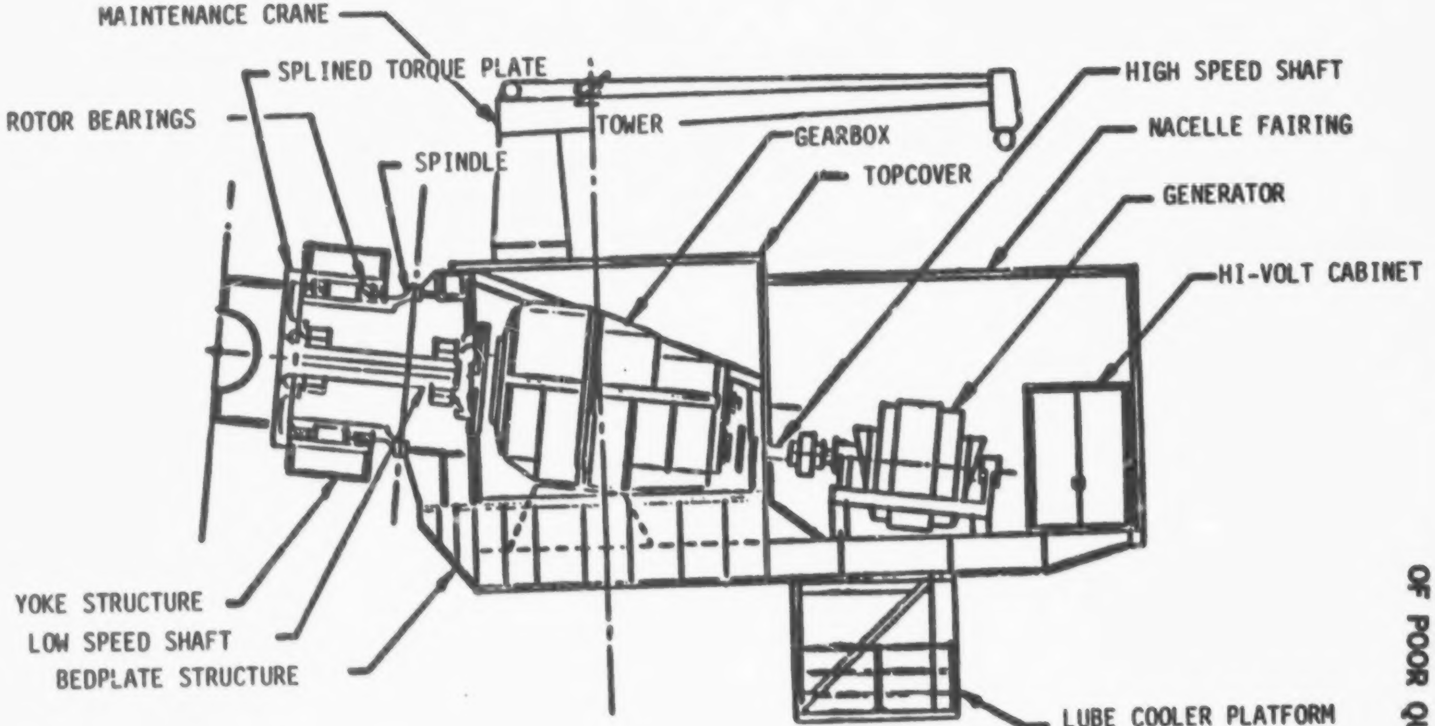
MAINTENANCE CRANE
SPLINED TORQUE PLATE
ROTOR BEARINGS
SPINDLE
TOWER
GEARBOX
TOPCOVER
HIGH SPEED SHAFT
NACELLE FAIRING
GENERATOR
HI-VOLT CABINET
YOKE STRUCTURE
LOW SPEED SHAFT
BEDPLATE STRUCTURE
LUBE COOLER PLATFORM

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Figure 18 Nacelle Assembly
with Yoke and Low Speed Shaft

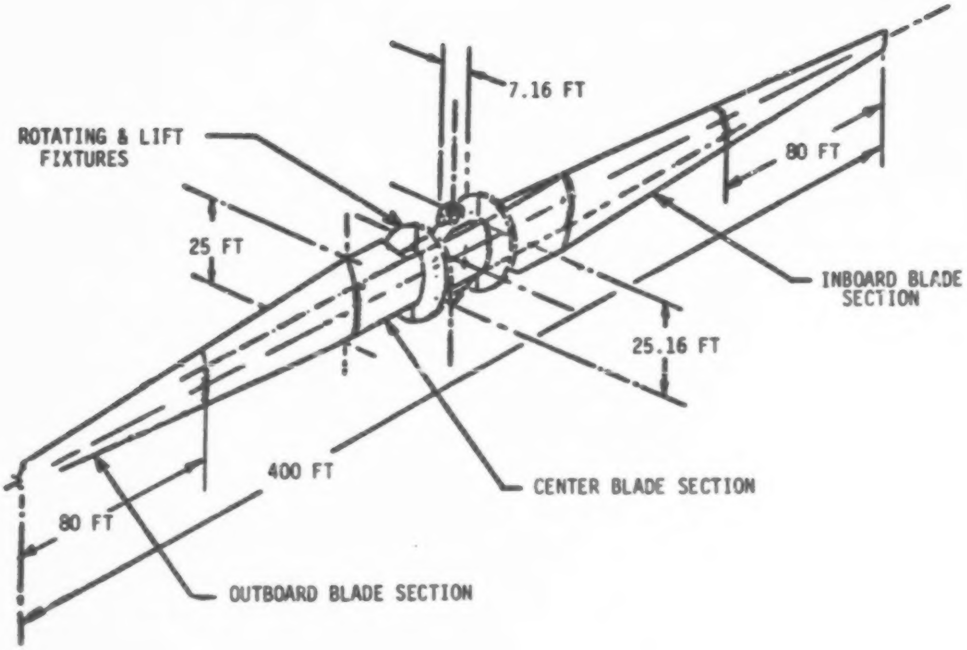

7.16 FT
ROTATING & LIFT FIXTURES
80 FT
25 FT
INBOARD BLADE SECTION
25.16 FT
400 FT
CENTER BLADE SECTION
80 FT
OUTBOARD BLADE SECTION

Figure 19 Blade Assembly

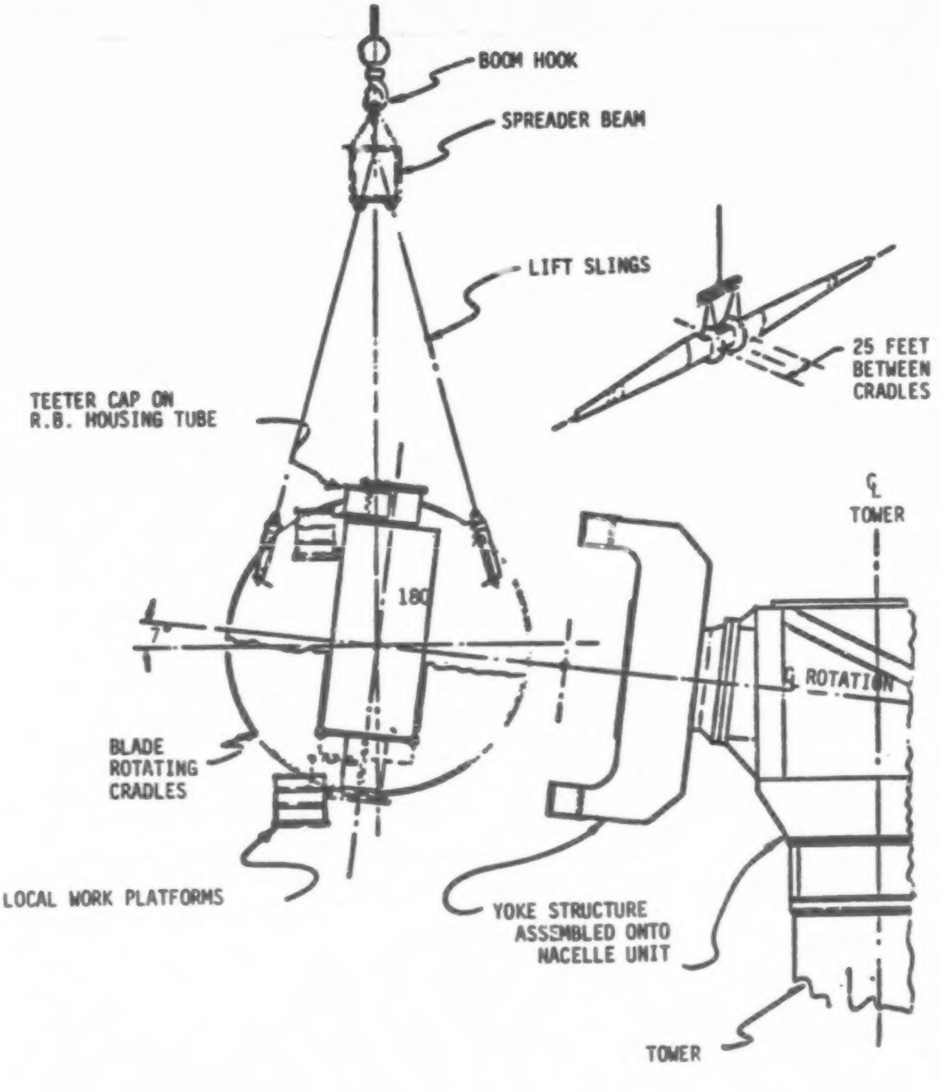
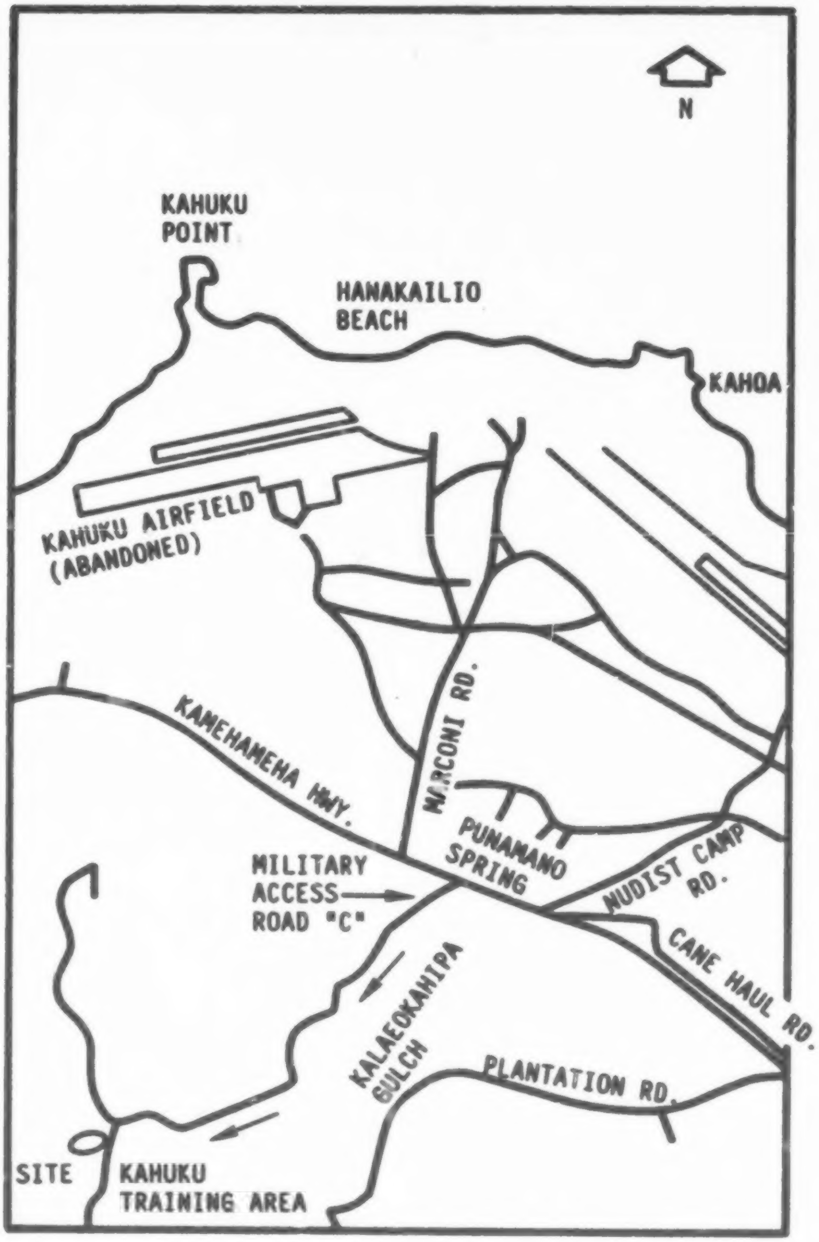

BOOM HOOK
SPREADER BEAM
LIFT SLINGS
25 FEET BETWEEN CRADLES
TEETER CAP ON R.B. HOUSING TUBE
℄ TOWER
180
7°
℄ ROTATION
BLADE ROTATING CRADLES
LOCAL WORK PLATFORMS
YOKE STRUCTURE ASSEMBLED ONTO NACELLE UNIT
TOWER

Figure 20 Blade Erection

EXHIBIT "E"

AREA MAP


N
KAHUKU POINT
HANAKAILIO BEACH
KAHOA
KAHUKU AIRFIELD (ABANDONED)
MARCONI RD.
KAMEHAMEHA HWY.
PUNAMANO SPRING
MILITARY ACCESS ROAD "C"
NUDIST CAMP RD.
CANE HAUL RD.
KALAEOKAHIPA GULCH
PLANTATION RD.
SITE
KAHUKU TRAINING AREA

Volume III
Book 2

ABBREVIATIONS

A	Amperes
AAO	average annual outage time
AASHTO	American Association of State Highway and Transportation Officials
ac	alternating current
ACI	American Concrete Institute
A/C	aircraft
AGMA	American Gear Manufacturers Association
AILSTAB	Aileron Stability Analysis
AISC	American Institute of Steel Construction
ASCE	American Society of Civil Engineers
ASCII	American Standard for Computer Information Interchange
ASTER	a computer program
ASTM	American Society for Testing Materials
AWG	American Wire Gauge
AWS	American Welding Society
baud	the rate of transmission of data from one part of computer to another
BESD	backup emergency shutdown
CBI	Chicago Bridge and Iron
CD	coefficient of drag
CDS	controls data system
CEC	control electronics cabinet
ccw	counterclockwise
cfm	cubic feet per minute
CGT	crack growth threshold
CI	cut-in
CIS	cycle intercept stress
CMD	command
COE	cost of energy
COV	coefficient of variation
CPU	central processing unit
CRT	cathode ray tube
CVN	Charpy V-notch test
dc	direct current
DOE	Department of Energy

ECL	Eptak control language
EHD	elastohydrodynamic
EMC	equivalent moisture content
ES	engineering instrumentation system
EPTAK	trade name for controller from Eagle Signal Division of Gulf and Western Industries
EMI	electromagnetic interference
ESD	emergency shutdown
FMEA	failure modes effects analysis
fpm	feet per minute
fpy	failures per year
FRP	glass fiber-reinforced plastic
ft.	feet
g	a unit of acceleration, equal to 32 ft/sec or 9.8 m/sec
G	giga, a prefix meaning one billion
gal.	gallons
GBI	Gougeon Brothers Incorporatedde
GETSS	GE Turbine System Analysis
GETSTAB	a computer program
gpm	gallons per minute
Hz.	Hertz
IITRI	Illinois Institute of Technology, Research Institute
I/O	input/output
in.	inch
ISM	input signal manager
k	kilo, a prefix meaning 1000
kips	a unit of force or weight, kilopounds, or 1000 pounds
ksi	a unit of stress, kips per square inch, or 1000 psi
kV	kiloVolts, or 1000 Volts
kW	kiloWatt or 1000 Watts
kWh	kiloWatt-hours, or 1000 Watt-hours
lbs.	pounds
lb/MDGL	pounds per 1000 square feet of double glue line
LEFM	linear elastic fracture mechanics
LMC	laminae moisture content
LVDT	linear variable differential transformer

m	milli, a prefix meaning .001
M	mega, a prefix meaning 1,000,000
mA	milliAmperes, or .001 of an Ampere
MC	moisture content
ml	milliliter
mph	miles per hour
mps	meters per second
MTBF	mean time between failures
MTTR	mean time to repair
MS	structural margin of safety
m/sec	meters per second
mps	meters per second
MUX	multiplexer
MW	megaWatt, or one million Watts
MWA	megaWatt-Amperes, or a million Watt-Amperes
N	Newton, the unit of force in the metric system
NASA	National Aeronautics and Space Administration
NASTRAN	a computer program
NDT	Nil-ductility transition
NEMA	National Electrical Manufacturers Association
N-m	Newton-meter, the unit of moment in the metric system
NSD	normal shutdown
O&M	operating and maintenance
OIS	operational information system
OSM	output signal manager
P	per revolution
PCS	pitch change system
PGC	Philadelphia Gear Corporation
PSC	partial span control
PIR	progarm information report
PLV	pitch line velocity
ppm	parts per million
PROM	programmable read only memory
psf	pounds per square feet
psi	pounds per square inch
PWHT	post-weld heat treatment
QAERO	a computer program

R	ratio of actual stress to allowable stress, or minimum fatigue stress cycle to maximum fatigue stress cycle
rad/sec	radians per second
RAM	random access memory
RAM	reliability, availability, and maintainability
RFP	request for proposal
RMC	root mean cubed
ROM	read only memory
rpm	revolutions per minute
RT	room temperature
SCAMP	Stiffness Coupling Approach Modal-Synthesis Program
SCI	Structural Composites, Incorporated
SIM-5A	a computer code for control system analysis
S_{min}	minimum stress
s_{max}	maximum stress
S-N	stress vs. number of cycles
SOW	Statement of Work
STRAP	Static Row Analysis Program
ssu	Saybolt univeral seconds
TBD	to be determined
TBR	to be resolved
TFT	transverse filament tape
TRAC	Transient Rotor Analysis Code
tty	teletype
TVI	television interference
UBC	Uniform Building Code
UPS	uninterruptible power supply
UDRI	University of Dayton Research Institute
V	Volts
Vac	alternating voltage
Vdc	constant voltage
W	Watts
WEPO	Wind Energy Project Office
WTG	wind turbine generator
WT	weight
WINDLD	a computer program
WINDOPT	a computer program

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16. Abstract

This report documents the design, development and analysis of the 7.3MW MOD-5A wind turbine generator covering work performed between July 1980 and June 1984. The report is divided into four volumes: Volume I summarizes the entire MOD-5A program, Volume II discusses the conceptual and preliminary design phases, Volume III describes the final design of the MOD-5A, and Volume IV contains the drawings and specifications developed for the final design.

Volume III, Final Design and System Description, describes the performance and characteristics of the MOD-5A wind turbine generator in its final configuration. Each subsystem - the rotor, drivetrain, nacelle, tower and foundation, power generation, and control and instrumentation subsystems - is described in detail. The manufacturing and construction plans, and the preparation of a potential site on Oahu, Hawaii, are documented. The quality assurance and safety plan, and analyses of failure modes and effects, and reliability, availability and maintainability are presented.

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